Converter Topologies for Wired and Wireless Battery Chargers

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Overview

Timeline

- Start – FY11
- Finish – FY14
- 15% complete

Budget

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

Barriers

- Reducing onboard battery charger cost, weight, and volume
- Achieving high efficiency
- Meeting RF emission regulation and safety requirements

Partners

- ORNL team member: John Miller
- ORNL Measurement Science & Systems Engineering Div, RF, Communications & Intelligent Systems group
- ORNL vehicle systems group
- Energy Dynamics Laboratory

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
- Develop converter topologies suitable for wireless charging systems and design, build, and test prototypes

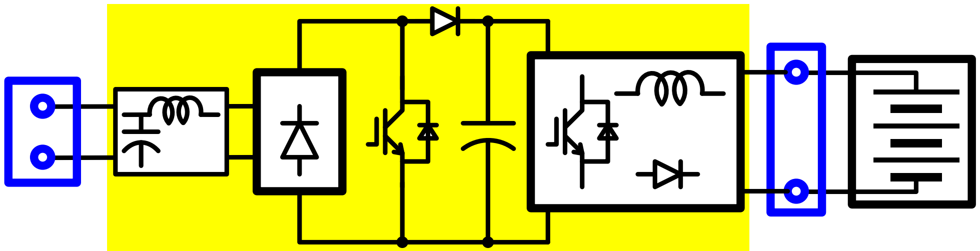
- FY11 objectives
  - Perform circuit simulation study and generate a converter design for a 5 kW integrated wired charger
  - Develop converter topologies for wireless chargers through circuit simulation

Milestones

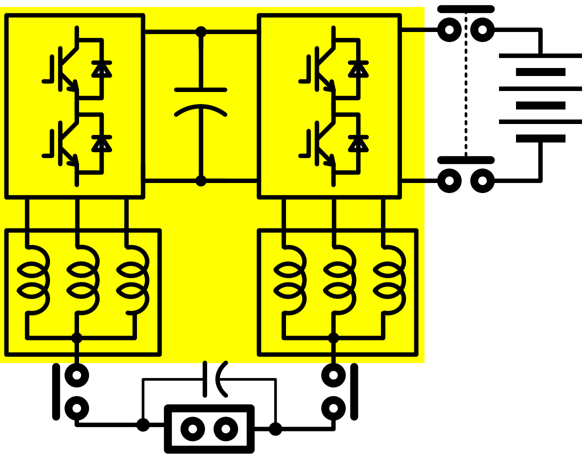
Month/Year	Milestone or Go/No-Go Decision
Sept-2011	Milestone: Complete the simulation study on selected converter topologies for both wired and wireless applications Go/No-Go Decision: If simulation results show potential for meeting efficiency and input power factor requirements, proceed to prototype development in FY12

The Problem and Approach (1) – *Integrated Wired Charger*

- 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)



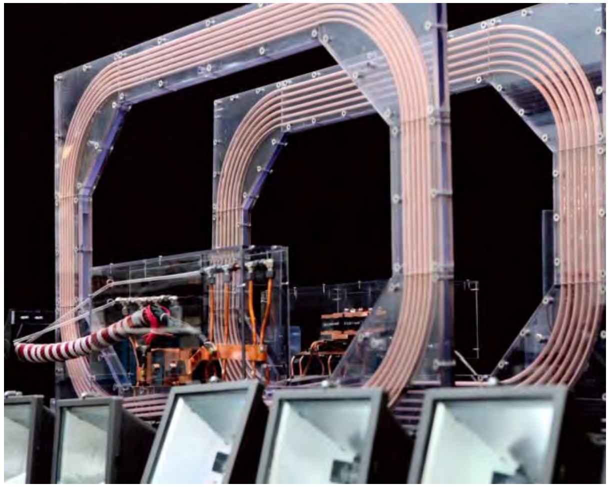
- The approach of using the on-board traction drive inverters and motors for charging the battery overcomes the issues with standalone battery chargers but
  - difficult to provide galvanic isolation to address safety concerns
  - cannot charge “dead” batteries



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

The Problem and Approach (2) – *Wireless Charger*

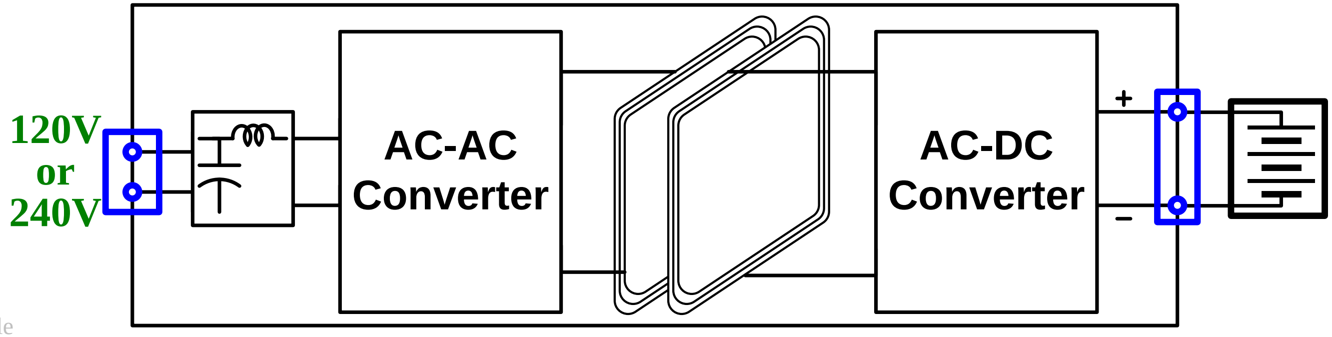
- In the long term, wireless charging systems are highly desirable for ultimate convenience and prevention of users' forgetting to plug in their vehicles
- A concept of using resonant air-core antennas for wireless charging is under investigation at ORNL
- The ORNL work focuses on antenna design and power transfer capability against the alignments of the antennas



- Converters with high efficiency and power factor and suitable for the wireless charging system are needed

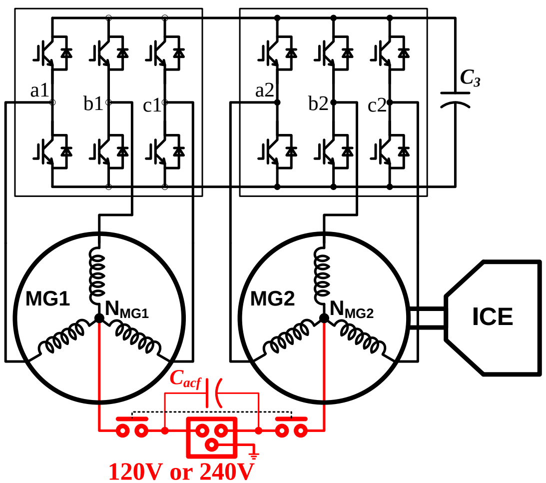
The Problem and Approach (3) – *Wireless Charger*

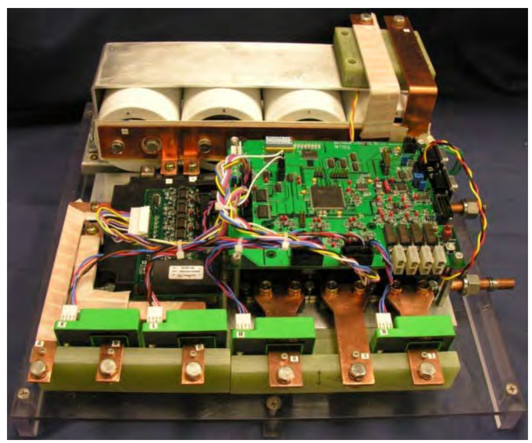
- Converters suitable for wireless charging systems will be investigated by simulation and bench tests. Converter topology candidates include
  - AC-DC plus DC-DC
  - AC-AC plus AC-DC
- Control methods for efficiency improvements will also be included
  - Alternative resonant modes that can significantly reduce circulating current
  - Soft-switching to reduce switching loss and EMI noises
  - Synchronous rectification to reduce conduction loss



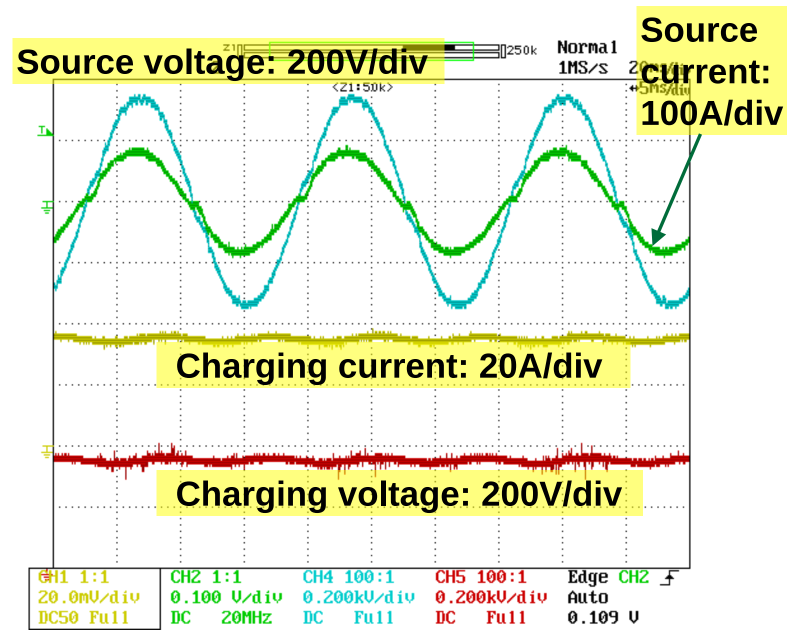
FY09 Technical Accomplishments (1) – Related work for wired charger

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





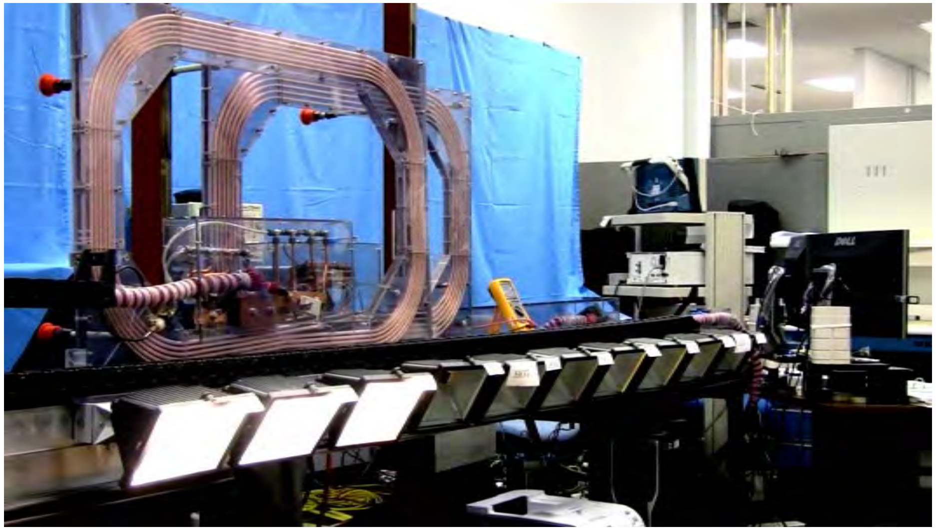
An integral charger prototype utilizing a traction drive comprised of a 55 kW motor inverter and a 30 kW generator inverter



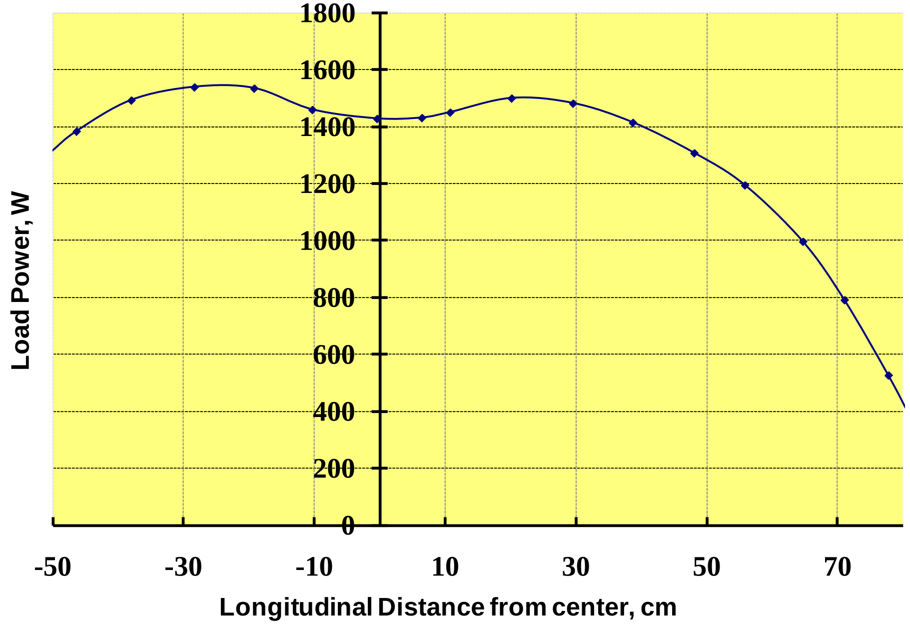
Waveforms for charging at 12.4 kW from a 240V source

FY10 Technical Accomplishments (2) – Related work for wireless charger

- An internally funded project has demonstrated wireless power transfers of up to 4 kW across a 10” airgap of two antennas at efficiencies (%) in the low 90’s depending on the operating frequency, power level and relative position of the antennas.



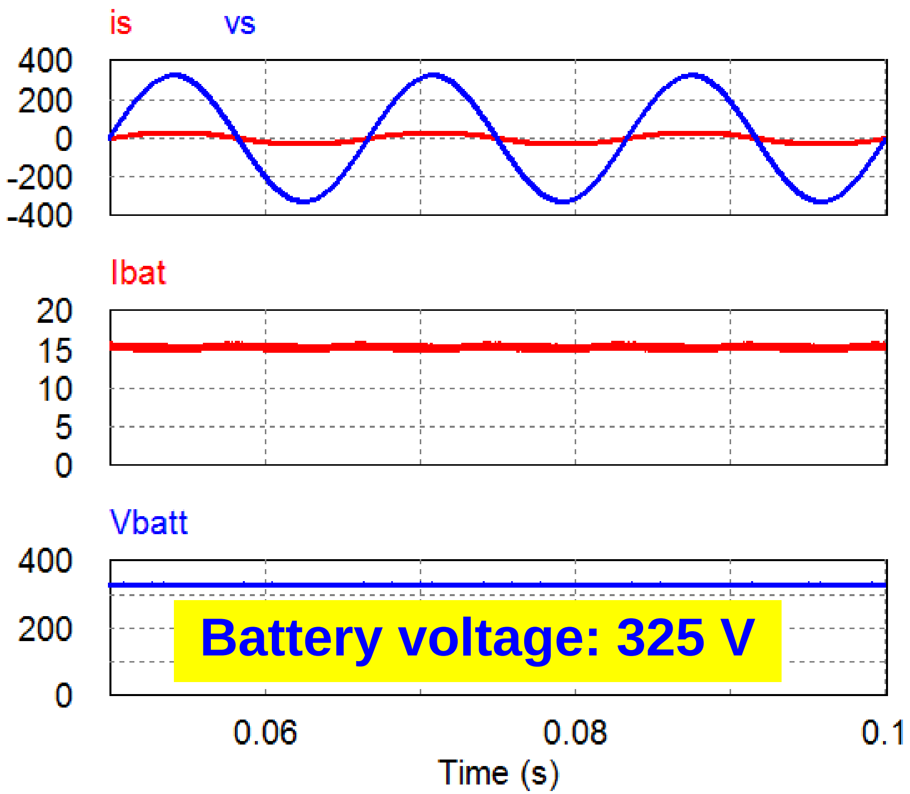
Laboratory test apparatus with alignment-adjustable antennas

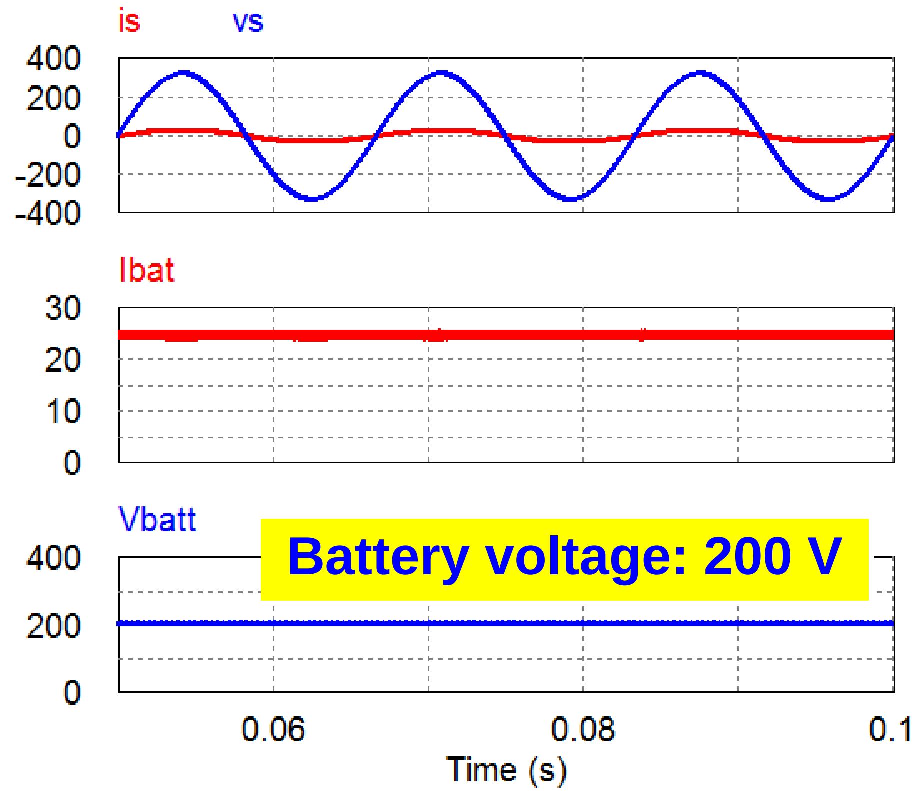


Power transferred as a function of longitudinal displacement with 25.4-cm coil spacing

FY11 Technical Accomplishments (3) – *Integrated Wired Charger*

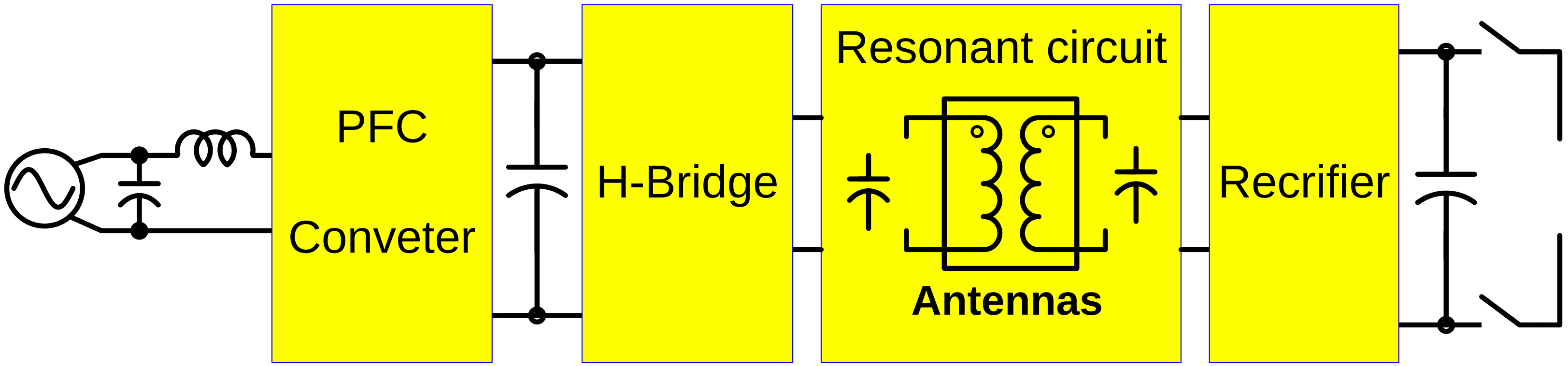
- Simulation results for charging at 5 kW from 240 V input
- Showing capability for charging at nominal and fully depleted battery voltage levels





FY11 Technical Accomplishments (4) –*Wireless Charger*

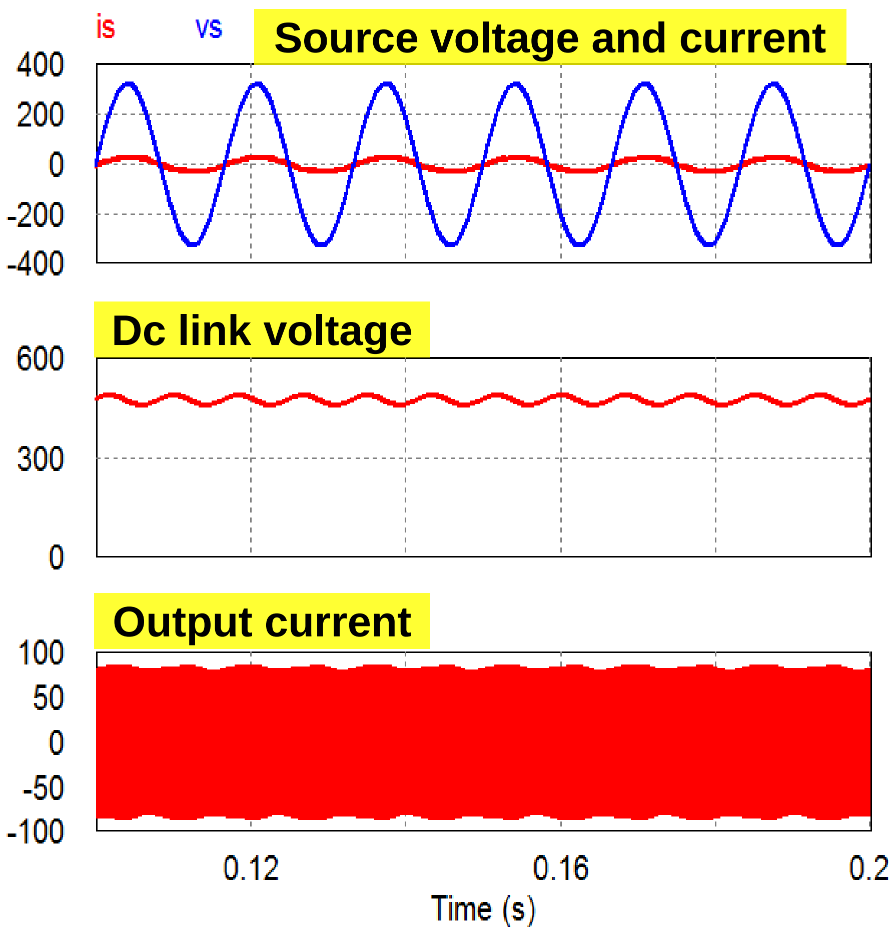
- Topology study
  – Simplified converter block diagram



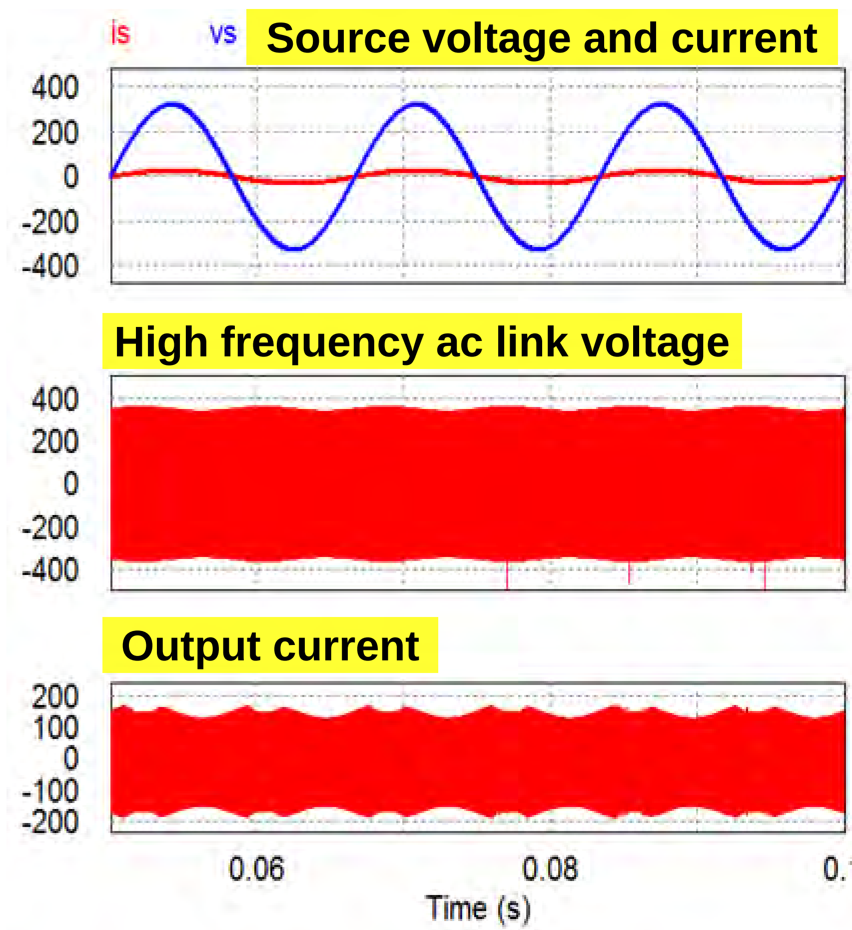
  – Two new topologies with reduced switch count are being investigated through modeling and simulation
    - 1st one based on AC-DC plus DC-DC
    - 2nd one based on AC-AC-DC
  – Resonant circuits to minimize reactive power requirement by increasing load power factor

FY11 Technical Accomplishments (5) *–Wireless Charger*

- Initial simulation results look promising



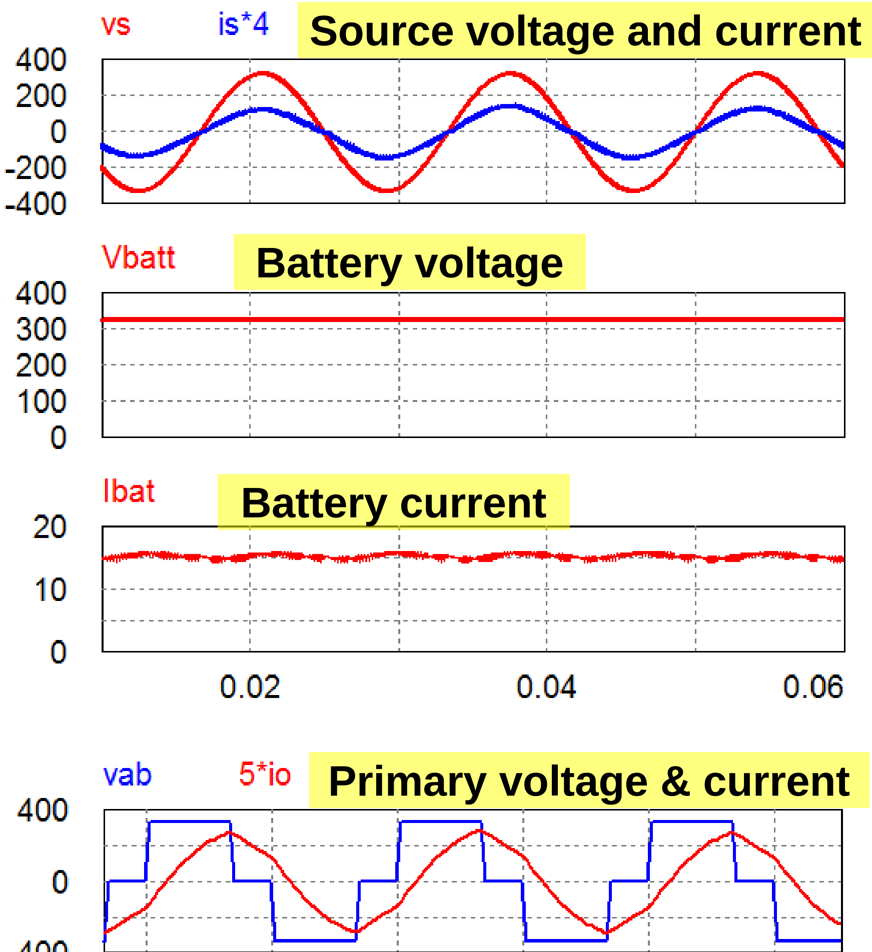
Simulation results for the AC-DC+ DC-DC converter



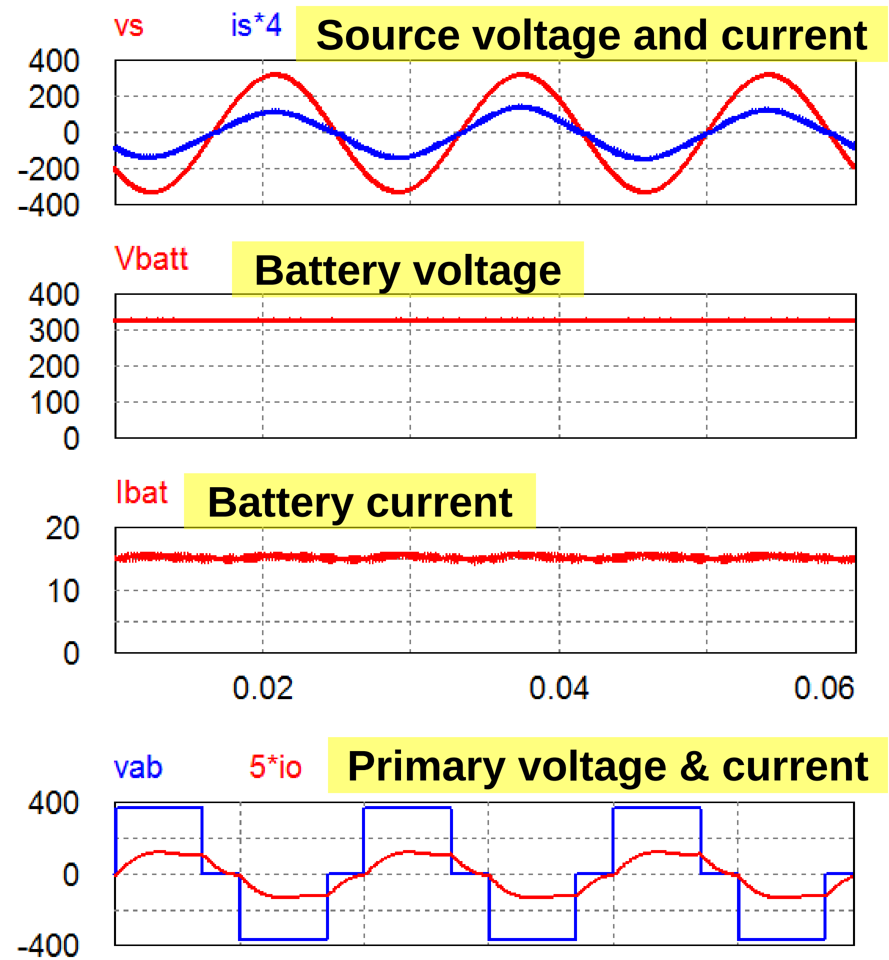
Simulation results for the AC-AC-DC converter

FY11 Technical Accomplishments (6) –*Wireless Charger*

- Resonant circuit to increase load power factor



Low load power factor



High load power factor

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Collaborations

- ORNL Measurement Science and Systems Engineering Division, RF, Communications and Intelligent Systems Group
  - Antenna design
  - RF emissions
- ORNL Vehicle Systems Group
  - Vehicle system requirements
- Energy Dynamics Laboratory
  - Inductive power transfer
- Will seek inputs from the EE Tech Team
  - The EE Tech team will be establishing technical targets for chargers in FY11

Future Work – Remainder of FY11

- Wired Charger
  - Complete the circuit simulation study of converter candidates for an integrated wired charger
  - Produce a conceptual design for a 5 kW prototype by incorporating the simulation results on component requirements and performance data
- Wireless Charger
  - Complete converter topology simulation study
  - Conduct a comparative evaluation of the converter topologies to down-select one for prototype development in FY12 using component requirements and performance data from the simulation study

Future Work — Beyond FY11

- FY12
  - Finalize design, build, and test a 5 kW integrated wired charger prototype
  - Design and build a 5 kW wireless charger converter prototype

- FY13
  - Refine the integrated wired charger design to improve power density by developing custom switch modules and high density converter packaging technologies
  - Test and characterize the 5 kW wireless charger converter prototype developed in FY12

- FY14
  - Refine the wireless charger prototype design to further performance improvements by incorporating advanced packaging technologies
  - Demonstrate a prototype in a vehicle charging system

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

- The wireless charging system offers ultimate convenience by eliminating user interventions and maximizes the utilization of the electrical ranges of PHEVs