Wireless Power Transfer Integrated Chargers

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Oak Ridge National Laboratory
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Overview

Timeline

- Start – FY17
- End – FY19
- 17% complete

Barriers

- Meeting EDT 2020 efficiency and power density targets while reducing system level costs
- Lifetime for the integrated dc-dc converter due to increased use of the boost converter

Budget

- Total project funding
  - DOE share – 100%
- Funding received in FY16: $NA
- Funding for FY17: $650K

Partners

- NREL
- ORNL team members: Zhiqiang Wang, Madhu Sudhan Chinthavali, and Veda Galigekere

Any proposed future work is subject to change based on funding levels

Objectives

- **Overall Objective**
  - To develop an optimized integrated wireless electric vehicle charging system which utilizes the boost converter of the electric drive train to meet DOE EDT 2020 power density and cost targets. The integrated wireless charger features:
    - Increased system level power density
    - Scalable for power levels up to of 55 kW
- **FY17 Objective**
  - Complete simulation study, analysis and system level design of 11 kW integrated wireless electric vehicle charging system as a part of a 55 kW electric drive train system
  - Implement secondary side control to attain increased interoperability
  - Design wireless power transfer coils which have a higher power transfer height ‘z direction’ to enable power transfer control for vehicle with different ground clearances
  - Integrate primary tuning circuit

Milestones

Date	Milestones and Go/No-Go Decisions	Status
Month 2016	Milestone: New start	
Month 2016	Go/No-Go decision: New start	
Dec. 2016	Milestone: Verified functionality of proposed integrated wireless charging architecture and 11 kW operation by simulation.	Met
Sept. 2017	Go/No-Go decision: If system design and analysis of 11 kW integrated wireless charger meet the DOE EDT 2020 targets, proceed to build the prototype in FY18.	On track

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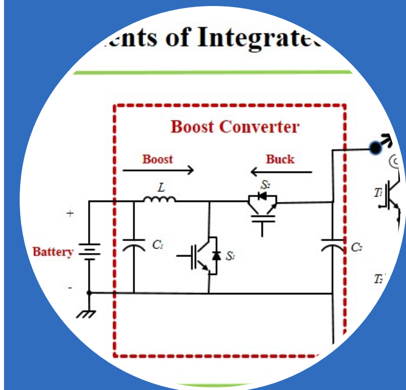
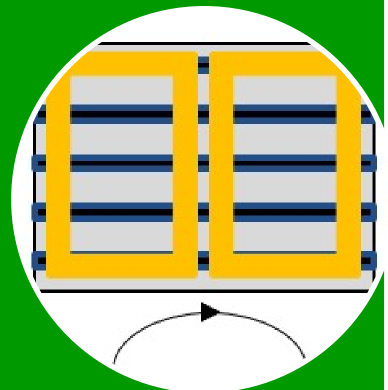
Approach/Strategy



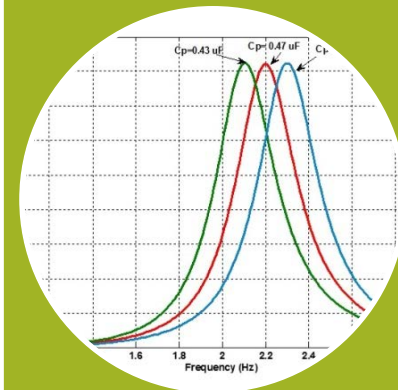
Topology

- Integrate boost converter of electric drive train into the wireless EV charger
- Select suitable primary and secondary resonant tuning architectures



Coil Development

- Design coils for high power transfer height
- Optimize the size of the vehicle coil
- Ensure compliance to safety standards



Sensitivity and Stability

- Evaluate sensitivity of performance as a function of coupling and load variation
- Analyze and determine stability criteria for integration of boost converter and wireless charging system

System Packaging

- Optimize the primary and secondary tuning elements
- Utilize high performance wide-bandgap based dc-dc converter
- Select optimal boost switching frequency
- Optimize filter component sizes

11 kW Integrated Wireless EV Charger

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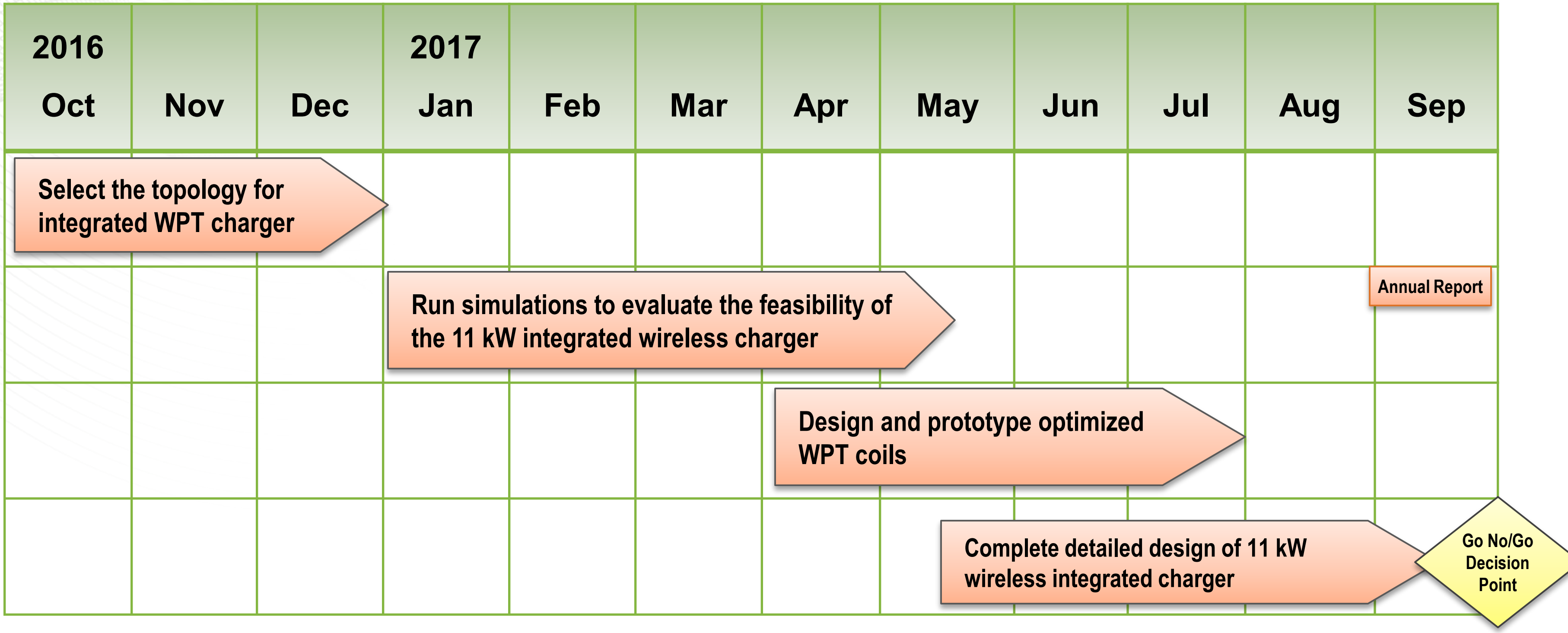
Approach FY17 Timeline



Go No/Go Decision Point: Evaluate feasibility of hardware realization to further the system towards DOE EDT 2020 power density targets and cost targets.

Key Deliverable: Project report on detailed simulation study and analysis of 11 kW integrated wireless EV charger, including metrics indicating feasibility on DOE EDT 2020 power density targets.

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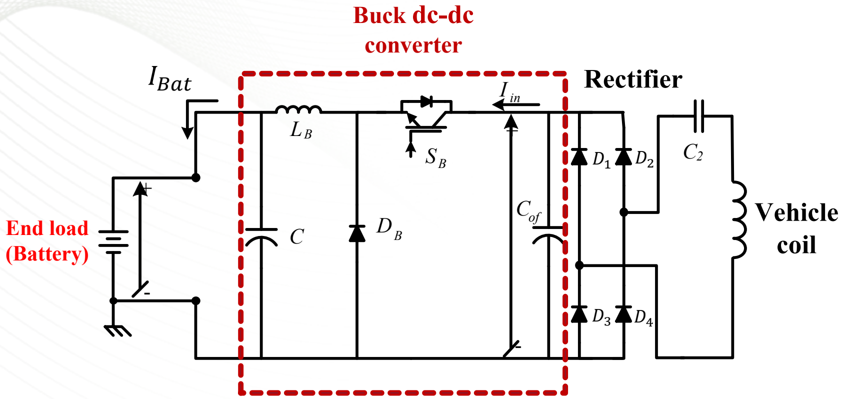
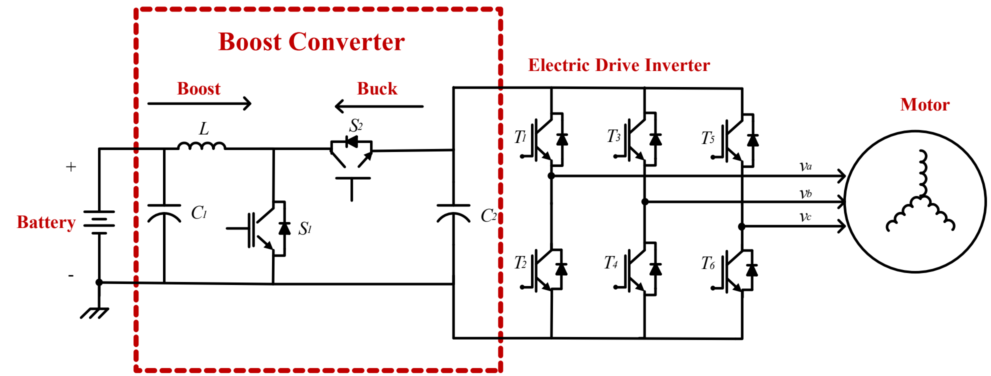
State-of-the-Art Wireless Charging System and Proposed Integrated Charger

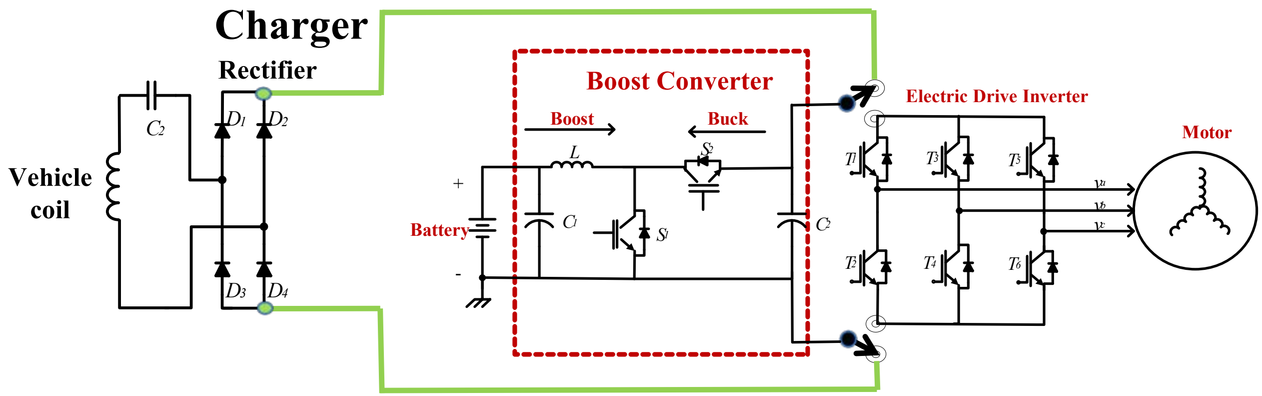
Onboard Components of Wireless EV Charger



Electric Drive Train with Boost Converter



Onboard Components of Integrated Wireless EV Charger

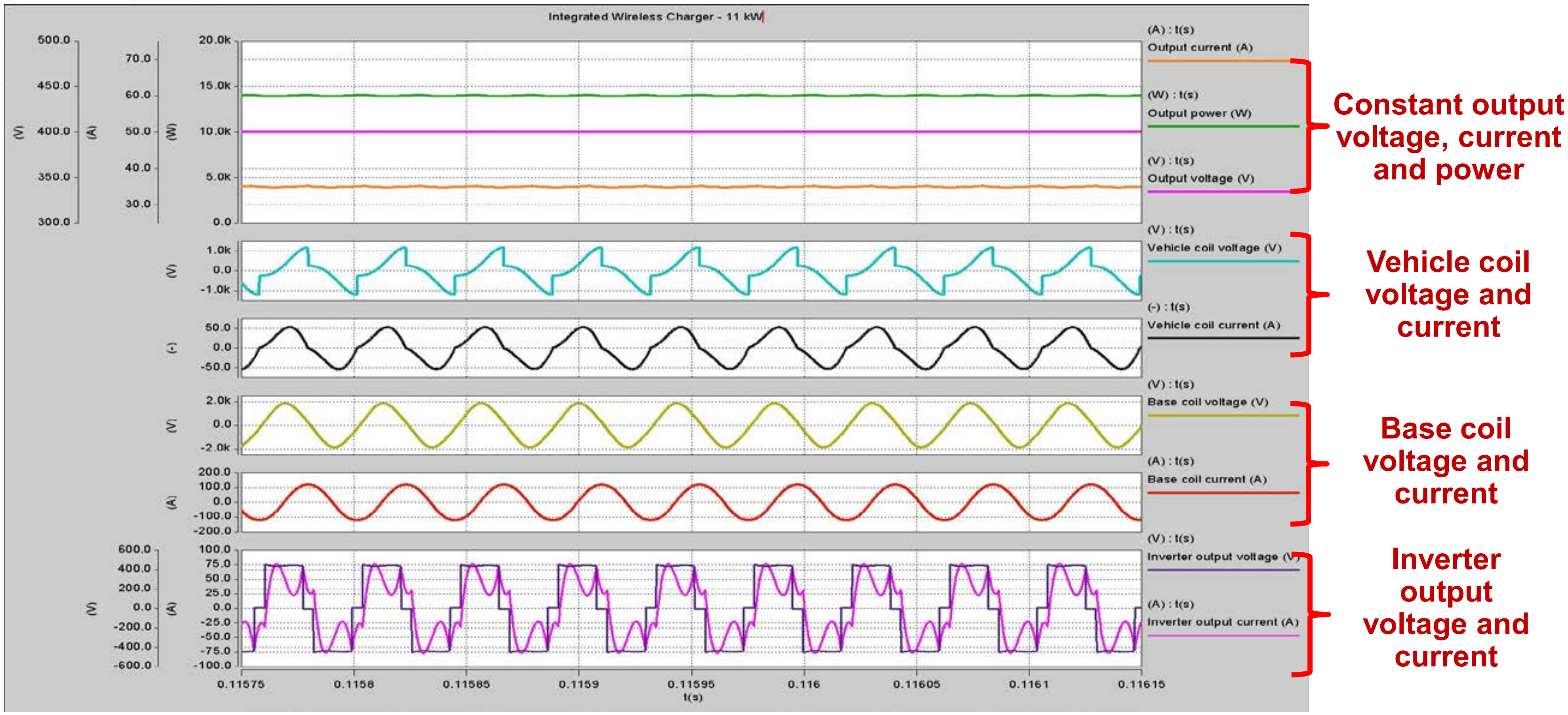


Advantages

- Minimal hardware changes – two relays needed
- Onboard footprint comparable to conductive charger
- Increased functionality of wireless charger – new topology allows secondary side power regulation

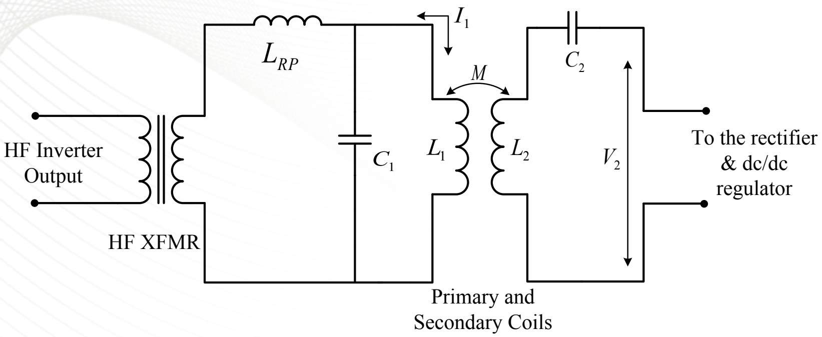
Technical Accomplishments – FY 2017
Simulation Study of 11 kW Integrated Wireless EV Charger

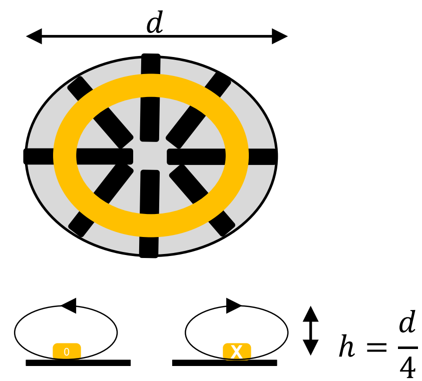
- Primary side load independent current source feature verified
- Secondary side regulation verified with no communication required between primary and secondary side

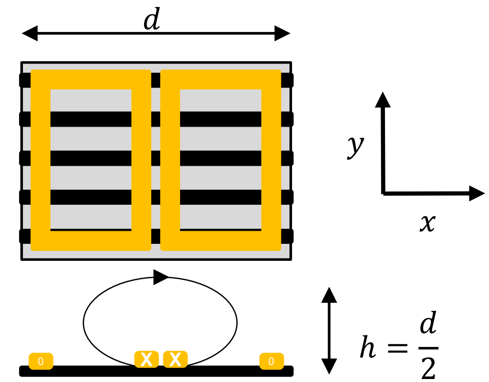


Verified functionality of 11 kW integrated wireless charger by simulation. Simulation results indicate feasibility.

Technical Accomplishments – FY 2017
Literature Search, WPT Coils, and Tuning Analysis







Circular primary coil **DD primary coil**

- LCL tuned primary enables secondary side control without wireless communication
- DD vehicle coil smaller than circular coil for the same performance
- Coil power density can be further optimized by using bifilar coils

Parameter	Circular	DD
Power transfer height	$\frac{d}{4}$	$\frac{d}{2}$
Vehicle coil size	Typically same as ground coil	Can be smaller than ground coil
Magnetic coupling null point*	At ~ 40 % of the pad diameter in x and y direction	At ~ 34 % of pad diameter along x axis and no null point along y axis

* Budhia, Mickel, et al. "Development of a single-sided flux magnetic coupler for electric vehicle IPT charging systems." *IEEE Transactions on Industrial Electronics* vol.60, no. 1, pp. 318-328, Jan. 2013.

Primary coil and tuning circuit have been selected to enable reduced coil weight and volume on the vehicle.

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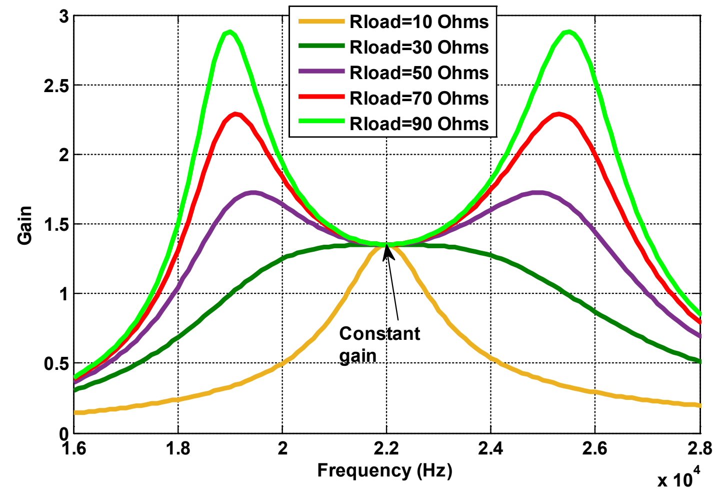
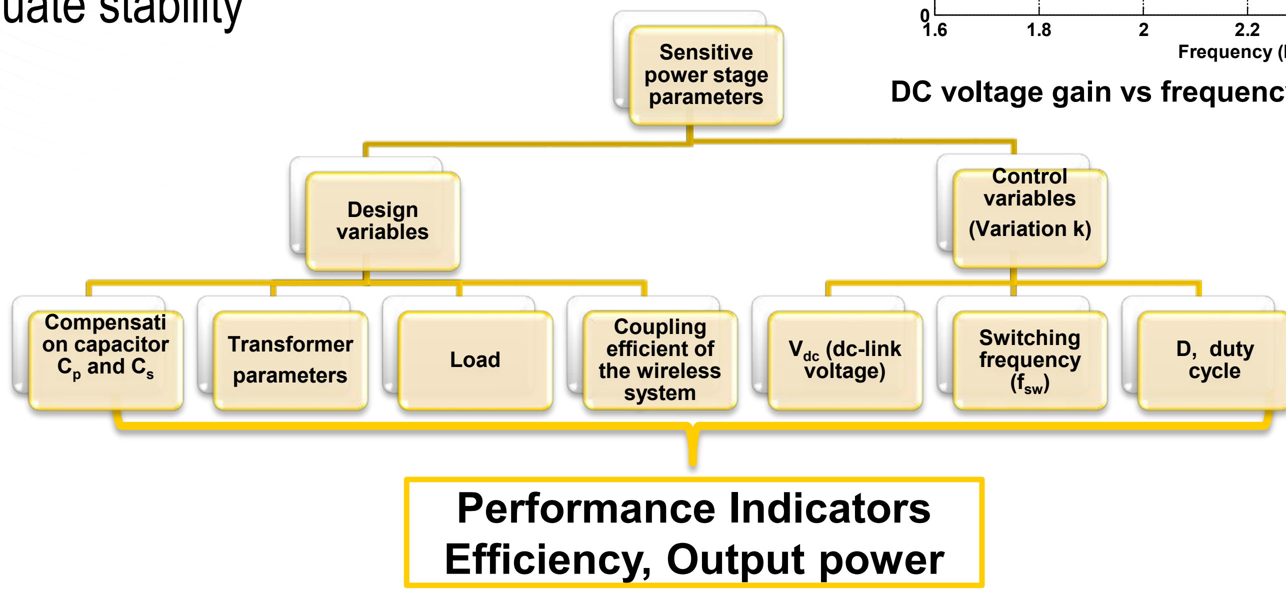
Technical Accomplishments – FY 2017
Sensitivity and Stability

- Identified parameters that can cause a drift in performance
- Analyzed effect of load and coupling variation on performance
- Identified dedicated hardware tests to evaluate stability



DC voltage gain vs frequency under different loads



Critical parameters causing sensitivity and stability issues have been identified and analyzed.

Technical Accomplishments – FY 2017
System Level Design for Higher Power Density

Parameters identified for optimizing the overall power density

- Higher frequency operation of dc-dc converter to reduce filter size
- Wide bandgap-device-based dc-dc converter leading to reduced thermal management required
- Optimized coil development to enable higher power transfer height with a smaller vehicle coil
- Stability analysis to evaluate the minimum filter capacitance required for stable operation

Key sub-system components have been identified to achieve overall reduction in weight and volume.

Responses to Previous Year Reviewers' Comments

This project is a new start

Collaboration and Coordination with Other Institutions

NREL – Thermal management

Remaining Challenges and Barriers for FY17

- Sizing of boost converter filter components for dual usage
- Switching frequency selection for optimal operation of electric drive train and integrated wireless EV charger
- Integration of relay into the integrated wireless EV charger
- Wide range of stable operation of the integrated wireless EV charger

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Proposed Future Work

- **Remainder of FY17**
  - Design 11 kW integrated WPT charger
    - Design power stage components – establish worst case operating stress on each component
    - Design high power transfer height capable coils
    - Optimize primary tuning architecture
    - Perform stability analysis of integrated wireless EV charger
- **FY18**
  - Design hardware of the integrated WPT charger with WBG dc-dc converter
  - Validate operation of 11 kW integrated wireless charger by hardware
- **FY19**
  - Evaluate scalability to 55 kW
  - Build a high power integrated wireless EV charger on track for wireless fast charging

Any proposed future work is subject to change based on funding levels

Summary

- **Relevance:**
  - Develop an optimized integrated wireless electric vehicle charging system which utilizes the boost converter of the electric drive train to meet DOE EDT 2020 power density and cost targets
- **Approach:**
  - Develop system level design of 11 kW integrated wireless electric vehicle charging system as a part of a 55 kW electric drive train system
- **Collaborations:** NREL
- **Technical Accomplishments:**
  - Selected power electronics integrated hardware architecture and tuning topology
  - Analyzed coil architecture to enable integration of wireless power transfer and electric drive train
  - Verified functionality and feasibility of an 11 kW integrated wireless charger
- **Future Work:**
  - Validate operation of 11 kW integrated wireless charger by hardware implementation in the laboratory
  - Evaluate scalability for 55 kW integrated wireless EV charger
  - Engage automotive Tier 1 suppliers and OEMs to explore commercialization of integrated wireless charger

Any proposed future work is subject to change based on funding levels