Project ID: VSS102

High Efficiency, Low EMI and Positioning Tolerant Wireless Charging of EVs

Allan Lewis
Hyundai America Technical Center Inc (HATCI)
15 May, 2013

2013 DOE Hydrogen and Fuel Cells Program and Vehicle Technologies Program Annual Merit Review and Peer Evaluation Meeting

Overview

Timeline
- Start date – Oct. 2012
- End date – Sept. 2015
- Percent complete – 10%

Budget
- **Total funding: $6,014,868.00**
  - Government* share: $4,215,593.00 (DOE obligations thru Oct 2013: $1,472,922.00)
  - Contractor share: $1,799,275.00
- Expenditure of Gov't funds in
  - FY13: ~$600,000.00 (10/12-current)

* Thank you to the DOE Vehicle Technologies program for their support and funding of this project

Partners

- Mojo Mobility

Technical Barriers

- Conductive charging stations introduce limitations regarding access, range, and usability.
  - ADA access
  - Cord length and inconsistent vehicle port placement
  - Overall usability
- Wireless charging systems are prone to EMI, position intolerance, and low efficiency.

Technical Targets

- Transfer power at over 6.6kW.
- Total system efficiencies of more than 85%.
- Achieve real world position and gap tolerance.
  - ±0.5 m along the width of the vehicle.
  - ±1 m along the length of the vehicle.
  - Greater than 20 cm coil to coil gap.

Relevance

Objectives

The objective of this project is to develop, implement, and demonstrate a wireless power transfer system with total system efficiencies of more than 85%, power transfer at over 6.6 kW, and maximum lateral positioning tolerance that can be achieved while meeting regulatory emission guidelines.

Addresses Technical Barriers

- Reduce the dependence on conductive charging stations which will allow more convenience to the user, increased access and usability in support of ADA, and provide a charge with potentially no action required by the driver.
- Develop a wireless charging system that meets industry guidelines, while operating with position tolerance and efficiency of more than 85%.

Milestones

Month/ Year	Milestone or Go/No-Go Decision	Description
02/2013	Milestone	Design of Initial WPT Prototype System.
06/2013	Milestone	System Test and Corrections.
07/2013	Milestone	Design of Second Generation WPT Prototype System.
09/2013	Milestone	System Test and Corrections.
09/2013	Go/No-Go Decision	Demonstrate the wireless power transfer system and perform a power transfer of at least 6.6 kW with an efficiency of at least 85% with at least a 20 cm coil to coil gap.
12/2013	Milestone	Design of Third Generation WPT Prototype System.
05/2014	Milestone	Vehicle Integration and Test.
09/2014	Go/No-Go Decision	Demonstration of the wireless power transfer system integrated into an electric vehicle with performance as defined in phase 1 Go-No-Go criteria.
06/2015	Milestone	The Project team will build five WPT-enabled EVs based on the EV and WPT chargers using system specifications developed in Phase II.
09/2015	Milestone	The Project team will deliver one WPT-enabled EV and wireless charging station to the Department of Energy for National Laboratory testing.
09/2015	Milestone	The Project team will perform vehicle and product tests as specified in Test Plan and provide data to a DOE national laboratory as specified in the data collection plan.

Approach

Design

Regulatory Requirements and Standards

- SAE J2954 Wireless Charging Task Force.
  - Alignment & Communication.
  - Safety, Performance, Robustness Testing & Validation.
  - Magnetic Field Interoperability.
  - Verification Testing.
  - Bus Charging.
  - Frequency Determination & EMC/EMF Definition.
- SAE J2836/6 Wireless Charging Specific Use Cases.
- SAE J2847/6 Wireless Charging Specific Messages.
- SAE J2931/6 Wireless Charging Specific Protocols.

Modeling (Electrical and Magnetic System)

- Electrical system from AC outlet to DC into high voltage battery.
- Electromagnetic models of receiver and transmitter coils and magnetics.
- Combining the coil and magnetics modeling with the electrical model
- Optimize total system

Prototyping

- Initial modular design leading to increased integration.

Approach (contd.)

Hardware and Software Systems

- System designed for power level flexibility.
- System designed to interface with vehicle onboard battery and charge system.
- Charger and receiver coil alignment systems.
- Receiver Identification, Error or Fault handling, End of Charge, etc.

Efficiency Considerations

- Material, geometry, component selection.
- Feedback control

EMI Mitigation

- Charger and receiver coil and magnetics design.
- Board layout.
- Secondary system placement and packaging.

Mechanical Considerations

- Thermal issues, size, integration into vehicle.

Tolerance Enhancement

- Coil and magnetics design and geometry.

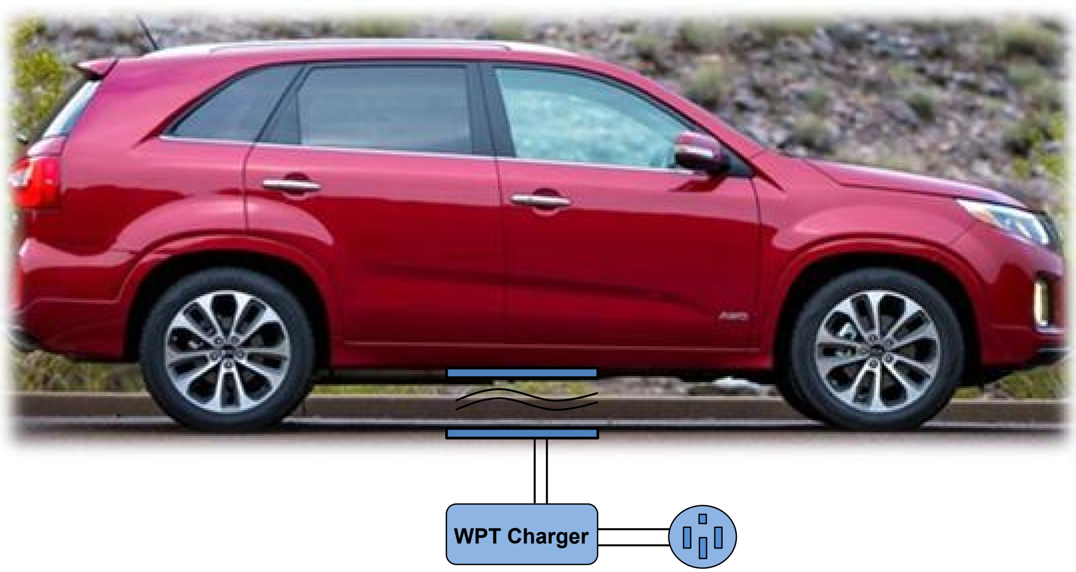
Verification Testing

- Power transfer rates.
- Efficiency.
- Position tolerance.
- Electromagnetic emission.

Approach (contd.)

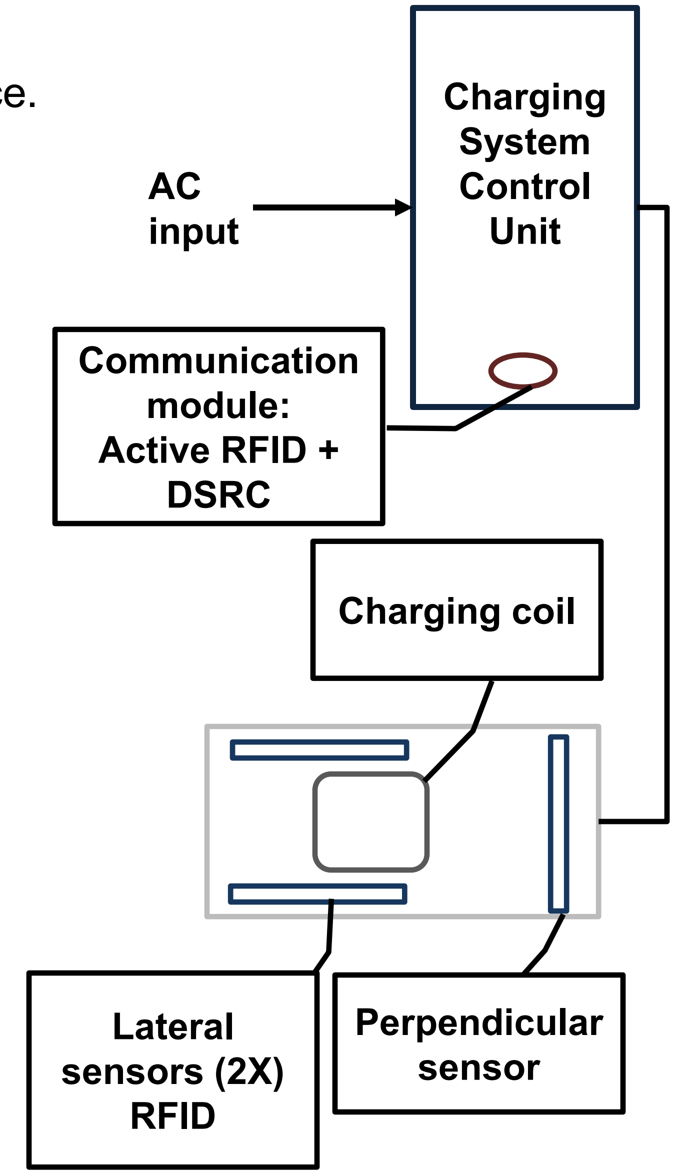
- Design and develop a grid connected electric drive vehicle wireless charging system that meets the expectations of low EMI, high position tolerance, and operates with high efficiency.

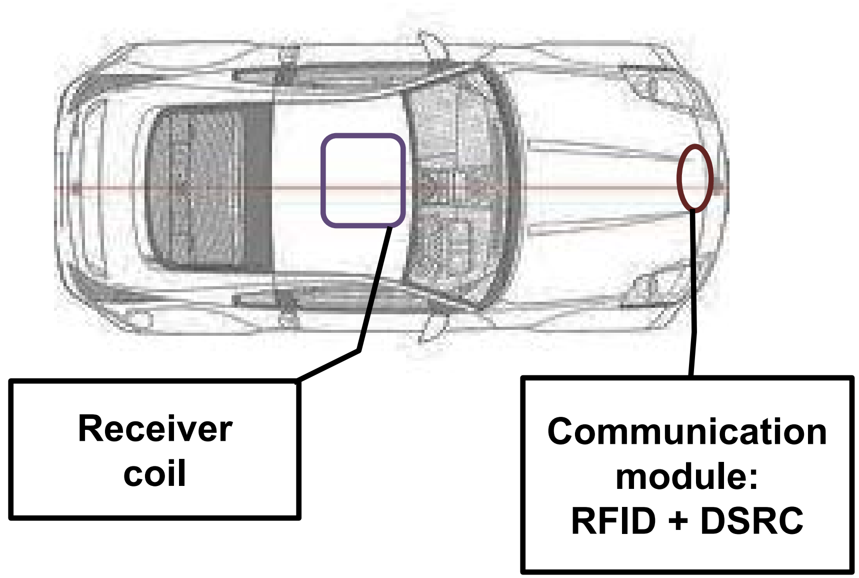
- System is being designed with the intent of commercialization.
  - Cost considerations throughout the design process.
  - Emphasis on simplicity and user convenience.
  - Phase 3 is dedicated to real world testing and customer validation.



Approach (contd.)

- The design of the system will provide inherent position tolerance.
- System will wake up based on proximity to vehicle and provide alignment aids to driver in cases of gross misalignment.
- All alignment and communication strategies in-line with SAE standardization works-in-progress.



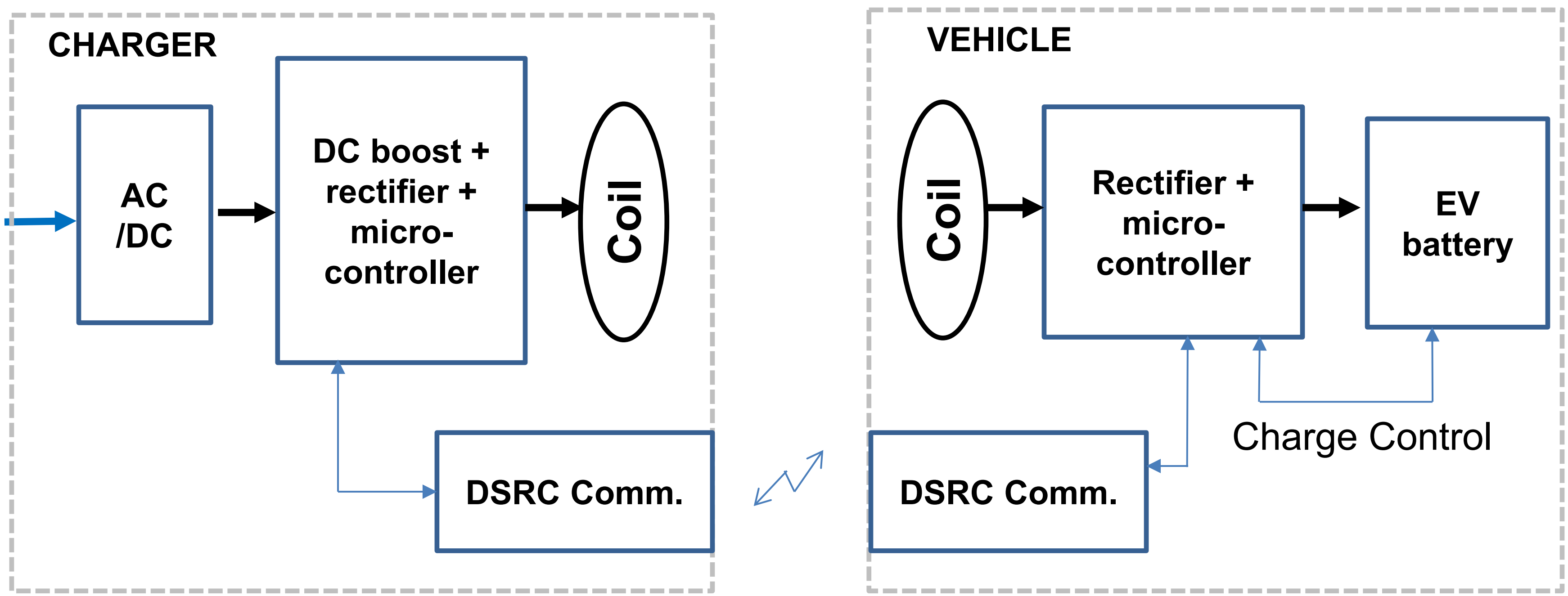


Technical Accomplishments and Progress

- Project kicked off in FY13.
- Defined end-to-end block diagram and control interfaces.
- Created accurate electrical simulations of power chain from AC input to DC supply to EV battery.
- Calculated power efficiency estimates of the system based on simulations and projections from Mojo Mobility low power wireless charging systems.
- Created preliminary electromagnetic models of receiver and transmitter coils.
- Simulated the electromagnetic fields in effort to optimize the wireless power transfer.

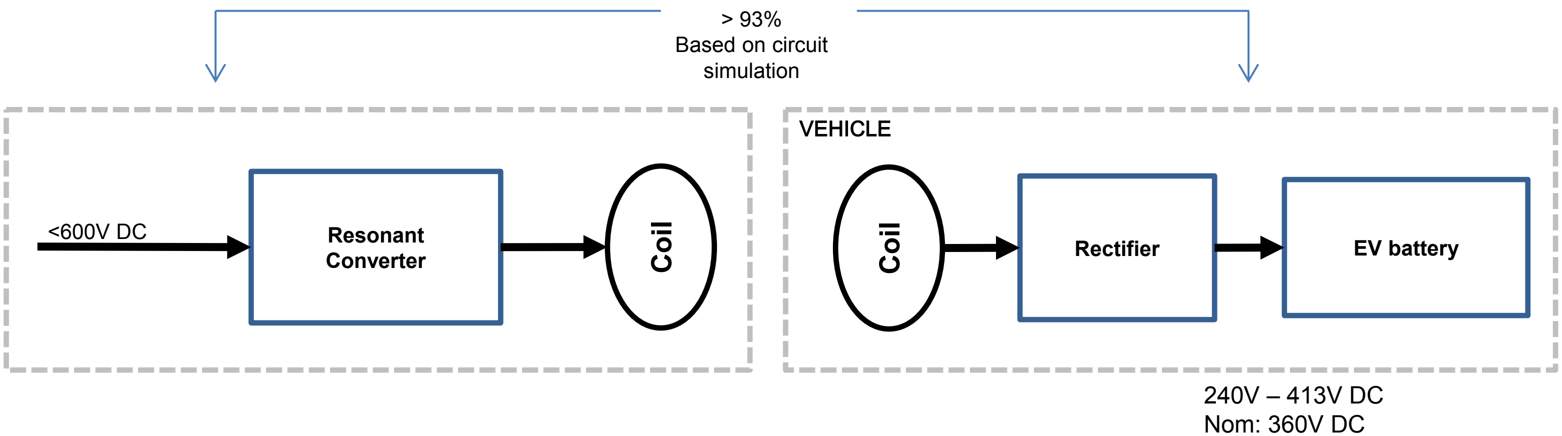
Technical Accomplishments and Progress (contd.)

- Basic system block diagram
  - Charger system
    - AC / DC converter; Voltage boost and Resonant Converter + Comms. & Control System
  - Vehicle system
    - Rectify high frequency power for HV battery charge + Comms. & Control System



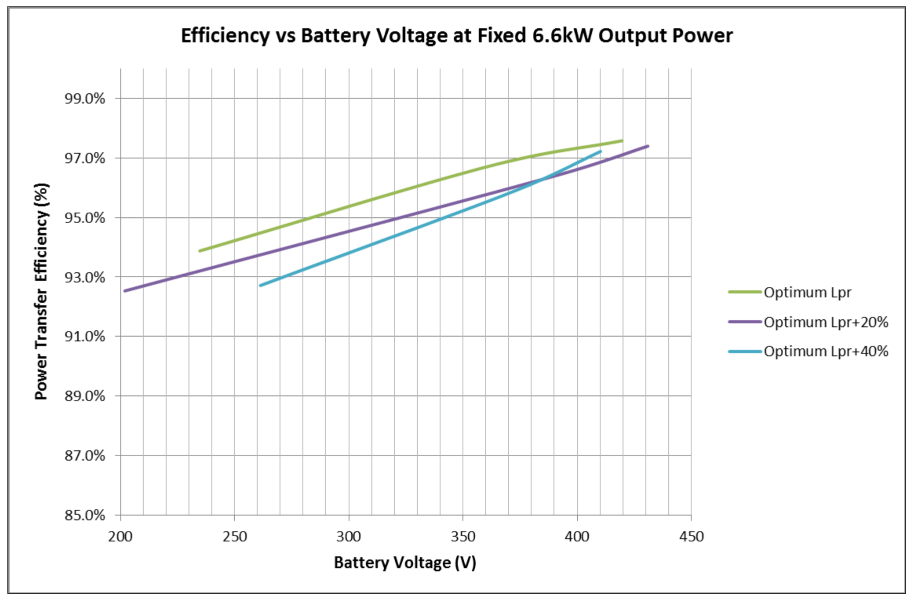
Technical Accomplishments and Progress (contd.)

Efficiency Estimates for Phase I – Part 1- DC to DC Conversion



Circuit Simulation Model of power transfer efficiencies from DC Charger input to DC Receiver output to EV battery

- Efficiencies exceeding 93% are anticipated
- EV Battery voltage ranges (240-413 V) can be achieved.
- Weak dependence on charger inductance is observed.



Collaborations and Coordination with Other Institutions

- Mojo Mobility
  - Sub-recipient of award no. DE-EE0005963.
  - Responsible for design, development of wireless charging system.
  - Currently developing wireless charging systems for consumer electronics, and automotive applications.

- Society of Automotive Engineers (SAE)
  - J2954 Wireless Charging Task Force (Voting Member)
  - J2836/6 Wireless Charging Specific Use Cases (Voting Member)
  - J2847/6 Wireless Charging Specific Messages (Voting Member)
  - J2931/6 Wireless Charging Specific Protocols (Voting Member)

- Next Energy
  - Advising on commercialization strategies and opportunities.
  - Market intelligence support.
  - Vehicle level functional validation support.

Proposed Future Work

- Remainder of FY13
  - First Generation System Test and Corrections.
  - Design of Second Generation WPT Prototype System.
  - Second Generation System Test and Corrections.
  - Complete Go/No Go milestone.

- FY14
  - Design of Third Generation WPT Prototype System.
  - Vehicle Integration and Test.
  - Complete Go/No Go milestone.

- FY15
  - The Project team will build five WPT-enabled EVs based on the EV and WPT chargers using system specifications developed in Phase II.
  - The Project team will deliver one WPT-enabled EV and charging system to the Department of Energy for National Laboratory testing.
  - The Project team will perform vehicle and product tests as specified in Test Plan and provide data to a DOE national laboratory as specified in the data collection plan.

Summary

The benefits provided by wirelessly charging Grid Connected Electric Drive Vehicles (GCEDV) are motivating innovation in the area to address technical challenges. The early design work by HATCI and Mojo Mobility is leading towards the ability to present new state of the art performance capabilities in the areas of:

- Low spurious unwanted emissions into the environment.
- High power transfer efficiencies.
- Large coil to coil misalignment and vertical gap separation.

The cooperation of HATCI and Mojo Mobility provides an opportunity to develop a next generation GCEDV wireless charging system that can be quickly integrated into production ready vehicles for vehicle level testing that will provide proof of concept systems for evaluation for commercial potential.

- Commercial Viability Study performed in FY14 will provide and understanding of the following considerations:
    - Commercial viability and cost benefits.
    - Comparison with SAE 1772 compliant conductive charging system.
    - Expected market penetration.
    - Potential petroleum reduction.