INL Testing of Wireless Charging Systems

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Advanced Vehicle Testing Activity (AVTA)

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Idaho National Laboratory

Overview

Timeline

- FY13 –Arrange NDAs, Obtain wireless charge(s) to test, prepare for testing in accordance with industry draft standards
- FY14 – Conduct Wireless Charger testing, analysis and reporting. Support further standards and test procedure development for Wireless Charging

Budget

- FY13 – $ 500k
- FY14 – $ 600k

Barriers

- Efficiencies of various advanced charging technologies are publicly undocumented and often measured differently
- Wireless efficiency predictions made without universal test procedures and definitions
- Compatibility / Interoperability and safety issues and potential cyber security vulnerabilities

Partners

- Industry partners
  - SAE J2954
  - Evatran LLC
- DOE Office of Energy Efficiency and Renewable Energy (EERE)

Objective / Relevance

- Provide unbiased and independent testing for:
  - Wireless charging systems
  - Conductive electric vehicle supply equipment (EVSE) as baseline for comparison to wireless charging systems
- Conduct benchmark testing of prototypes, field-deployed, and vehicle-integrated charging systems
- Provide DOE with feedback for technology development investments and FOAs (Funding Opportunity Announcements)
- Provide the charging, automotive, and electric utility industries with independent testing assessments and results
- Support industry's development of wireless charging standards and test procedures

Approach

- Scope: Provide Results from Testing
  - System Efficiency
  - Electric and Magnetic (EM) Field Strength
  - Impact on Grid (power factor, power quality, harmonics)
  - Foreign Object Detection and System Response / Tolerance
  - Performance at various power levels
  - Temperature (warm-up considerations for test procedures)
  - Support SAE J2954 wireless charging committee
    - Testing is conducted in accordance with the draft SAE J2954 test procedures
    - Test results and feedback are provided to SAE J2954 committee for document and procedure refinement

Approach continued

- Laboratory Testing
  - Open-air testing (off-board the vehicle)
    - Baseline test case (no metallic structure in proximity)
    - Does not include any effects or interaction with vehicle chassis or vehicle components

Approach continued

- Laboratory Testing
  - Reference Vehicle Floor-pan mock up (SAE J2954)
    - More representative to on-vehicle operation
    - Appropriate when no specific vehicle installation is available

Approach continued

- Full Vehicle Testing
  - On-vehicle testing (as installed and operated per manufacturer specifications)
    - Actual operation: specific to vehicle type and mounting specifications

Approach continued
Debris Tolerance and System Response

- System Response to debris
- Debris Temperature after 5 min.
  - Paper clips
  - Soda can
  - Aluminum foil
  - Rebar (3/8”)
  - Coins
  - Steel toe shoe
  - CD ROM disk
  - many more…

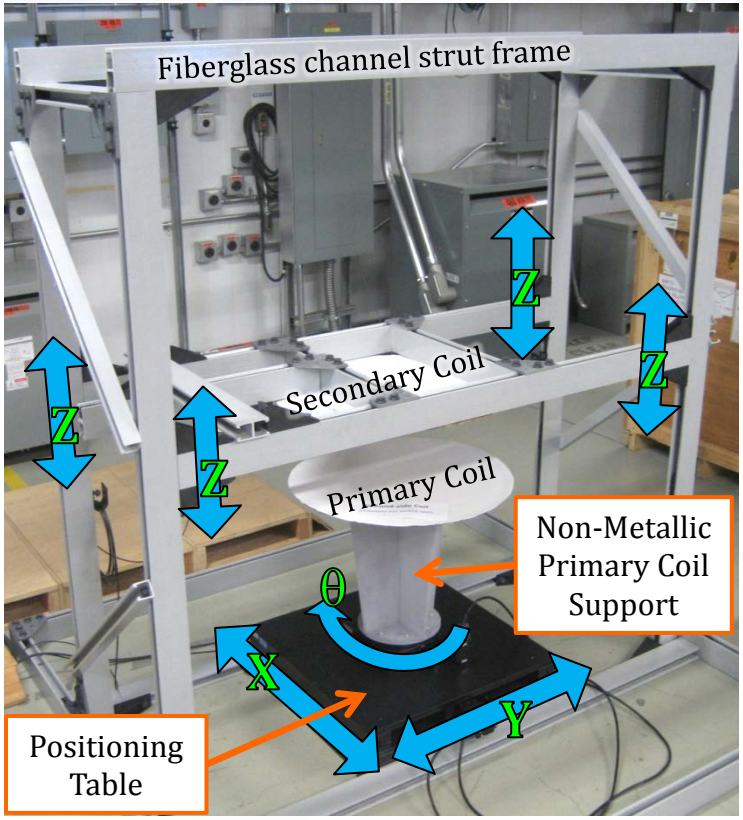
Milestones

Completed : Testing of Evatran's PLUGLESS wireless charger in coordination with the Apollo Demonstration Partnership

- Test Results
  - System Efficiency
  - Electric and Magnetic (EM) Field Strength
  - Impact on Grid (power quality, harmonics, etc.)
  - Foreign Object Detection and System Response / Tolerance
  - Performance at various power levels
  - Temperature (warm-up considerations for test procedures)
  - Support SAE J2954 wireless charging standards development
    - Testing conducted in accordance with draft SAE J2954procedures
    - Test results and feedback provided to SAE J2954 committee for document and test procedure refinement
- Baseline (Open-air testing off-board the vehicle)
- Reference Vehicle Floor pan Mock-up
- On-vehicle operational testing (as installed per manufacturer spec.)

Technical Accomplishments

- INL Charger test facility established
  - Programmable Loads
  - Hioki 3390 Power Meter
  - NARDA EM-field meter
  - FLIR SC640 Thermal Camera
  - Fiberglass channel strut frame with multi-axis positioning table
  - Custom LabVIEW test control and data acquisition



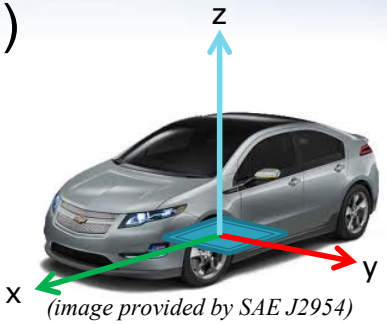
Test Complete: PLUGLESS™ Wireless Charging System from Evatran Group Inc.

- Rated power: 3.3 kW output (208 VAC input as tested)
- 30 A circuit breaker
- Nominal Gap between coils: 100mm (4.0”)
- Vehicle application: Chevrolet Volt (as tested)
- Dimensions:
  - Primary Coil (circular) above ground installation
    - Approx. Circular: 559mm dia. x 470mm long
  - Secondary Coil (oval) attaches under rear of vehicle
    - Rectangular: 464mm long x 525mm wide

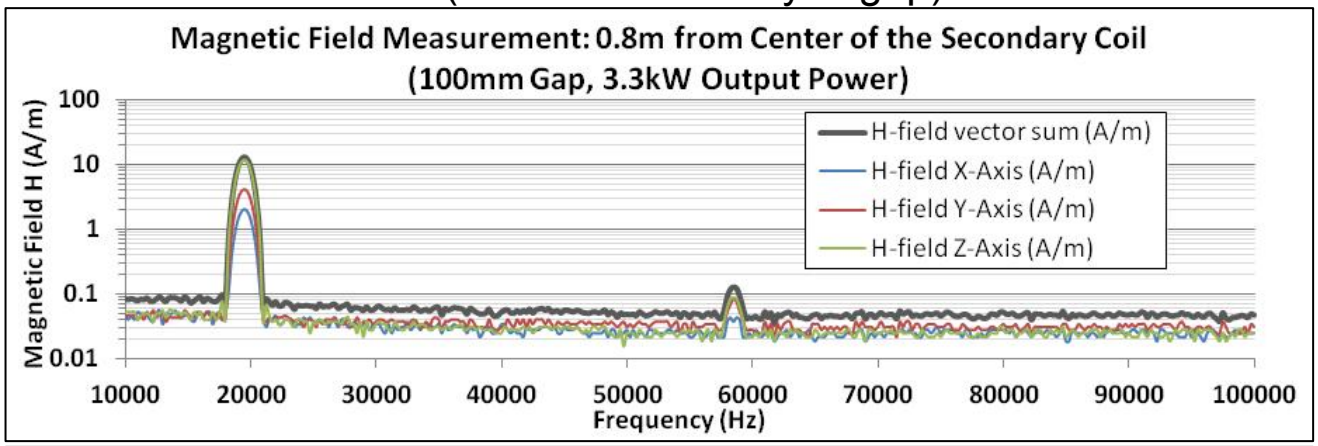
http://www.pluglesspower.com/wp-content/uploads/2013/06/PluglessL2_Specs.pdf

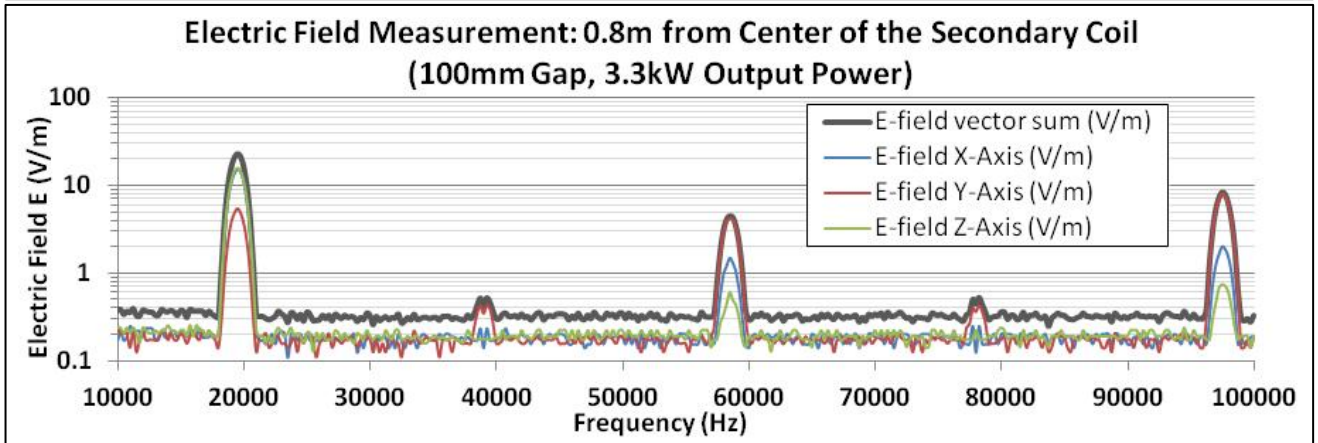
EM Field Frequency Scan 10kHz – 100kHz

- 100mm coil to coil gap, 3.3kW output power (nominal case)
- EM field measurement position (baseline test position)
  - X=0mm
  - Y=800mm (from the center of Secondary coil)
  - Z=-50mm (centered vertically in gap)



(image provided by SAE J2954)

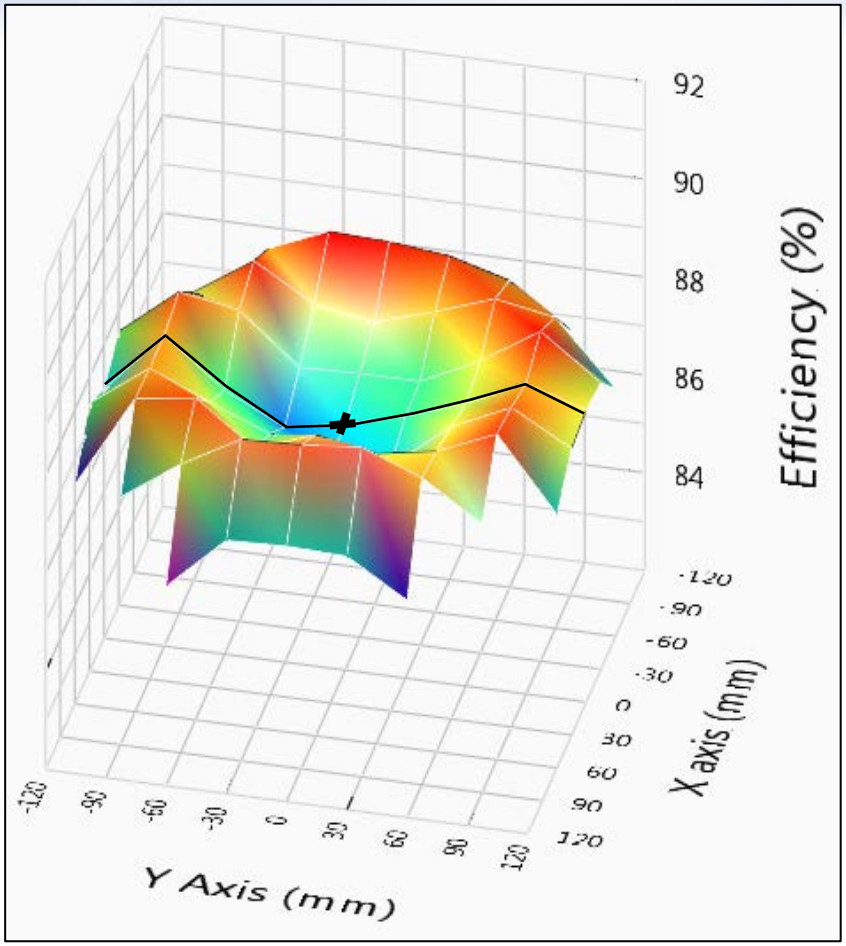




- Operating frequency
  - 19.5 kHz
- Peak Magnetic Field (H-field)
  - 12.9 A/m
  - (16.1 μT)
- Peak Electric Field (E-field)
  - 22.1 V/m

System Efficiency Variation with Coil Position

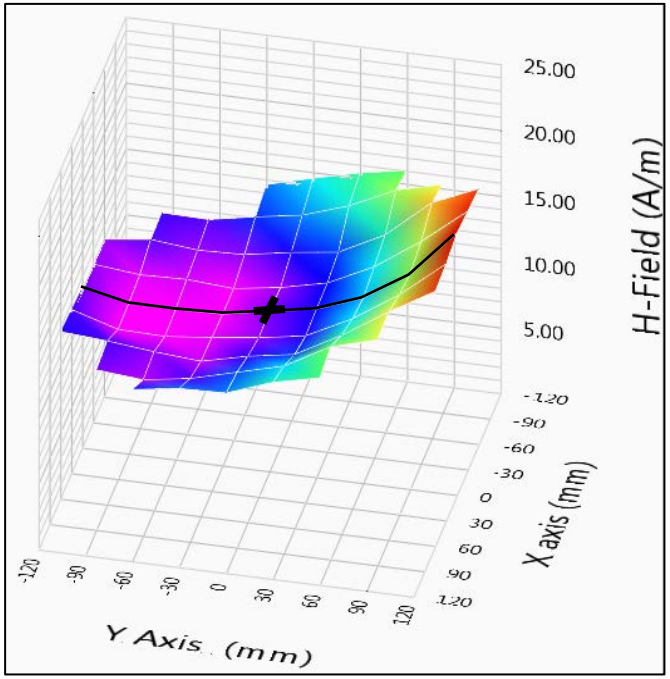
- 3.3 kW output power
- 100mm gap between coils
- X-axis and Y-axis show Primary Coil position relative to Secondary Coil

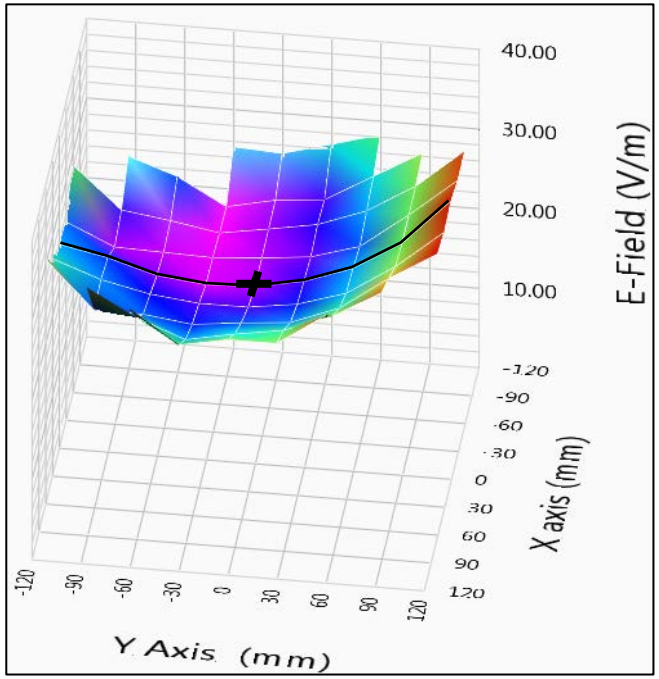


Efficiency Results (at 3.3 kW output with **100mm gap**)		Primary Coil position relative to Secondary Coil (mm)
Maximum Efficiency (%)	88.8%	(-90,-30)
Nominal Efficiency (%)	87.0%	(0,0)
Minimum Efficiency (%)	86.1%	(120,-60)

EM Field Variation with Coil Position

- 3.3 kW output power
- 100mm gap between coils
- X-axis and Y-axis show Primary Coil position relative to Secondary Coil

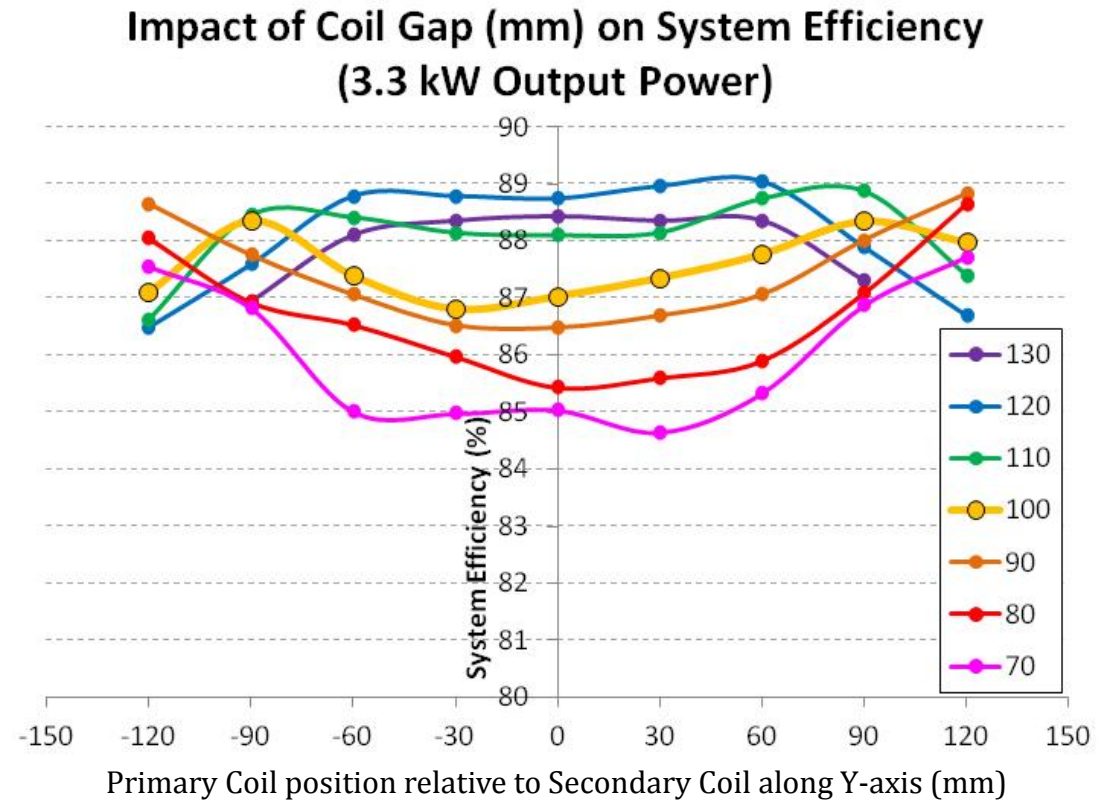


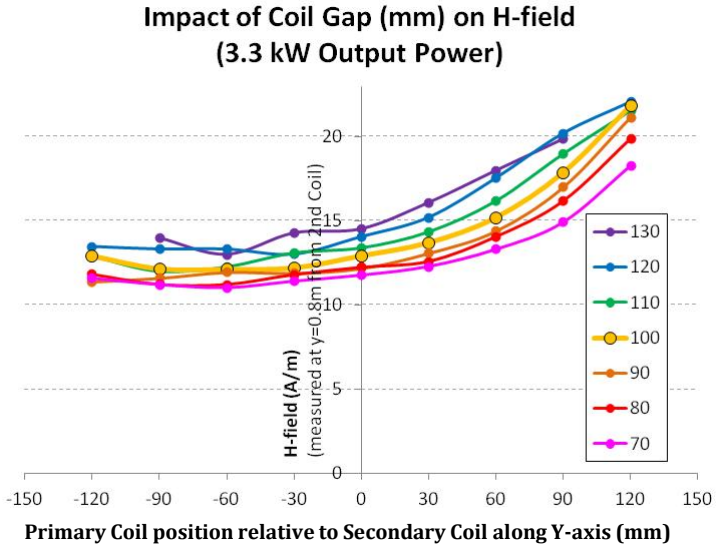


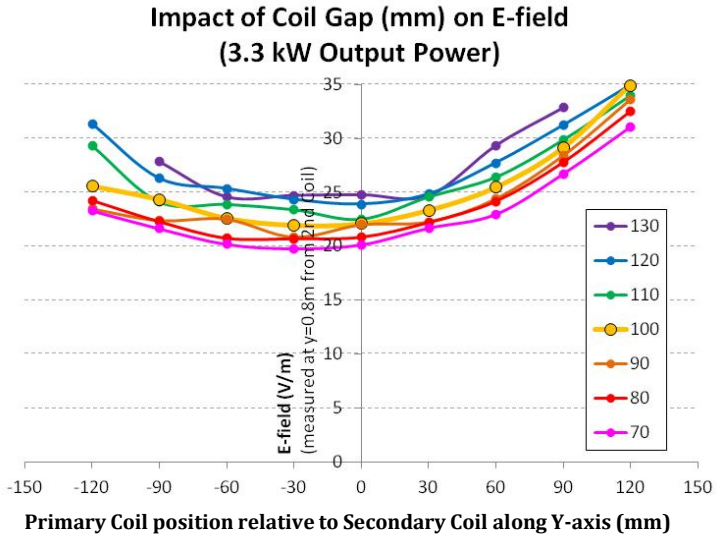
EM Field Results (at 3.3 kW output with 100mm gap)		Primary Coil position relative to Secondary Coil (mm)
Maximum H-field (A/m)	21.9	(0,120)
Nominal H-field (A/m)	12.9	(0,0)
Maximum E-field (V/m)	35.2	(60,120)
Nominal E-field (V/m)	22.1	(0,0)

Coil to Coil Gap Impact on System Efficiency and EM Field

- 3.3 kW output
- EM field measured at
  - X=0.0m Y=0.8m
  - Centered vertically in gap (Z=-50mm)

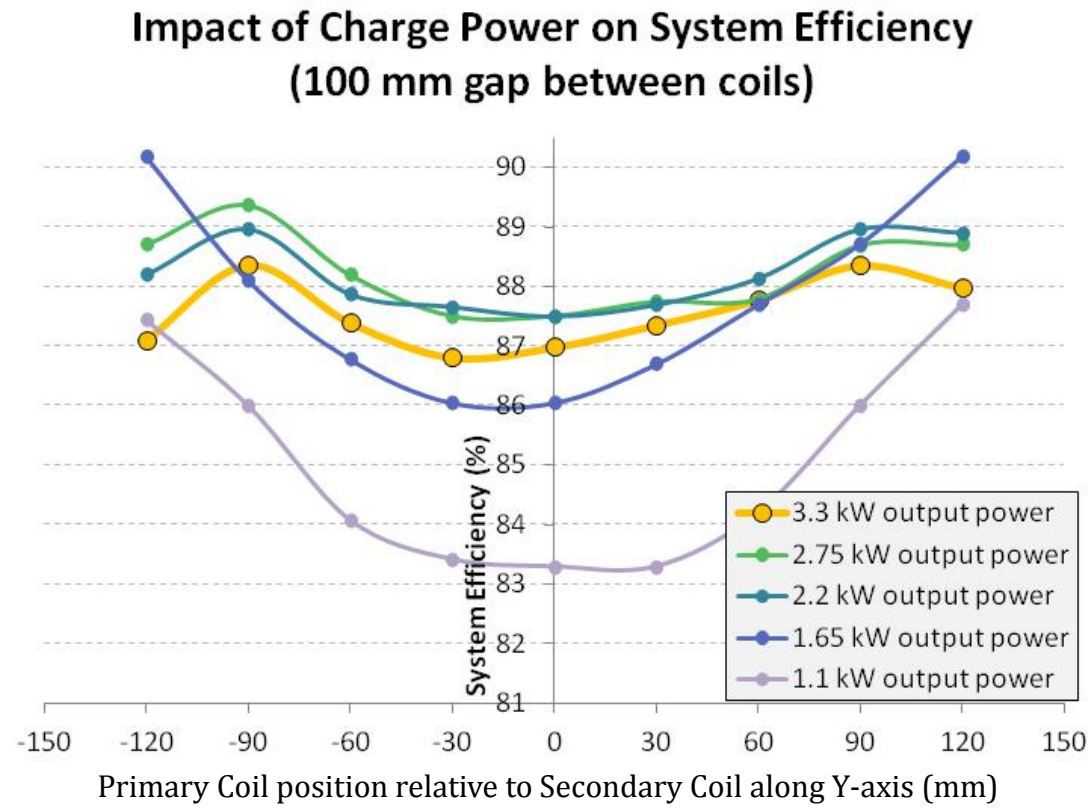


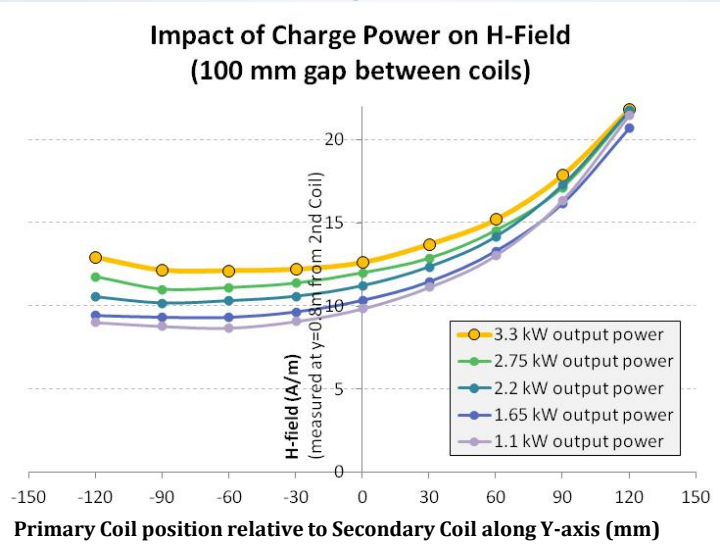


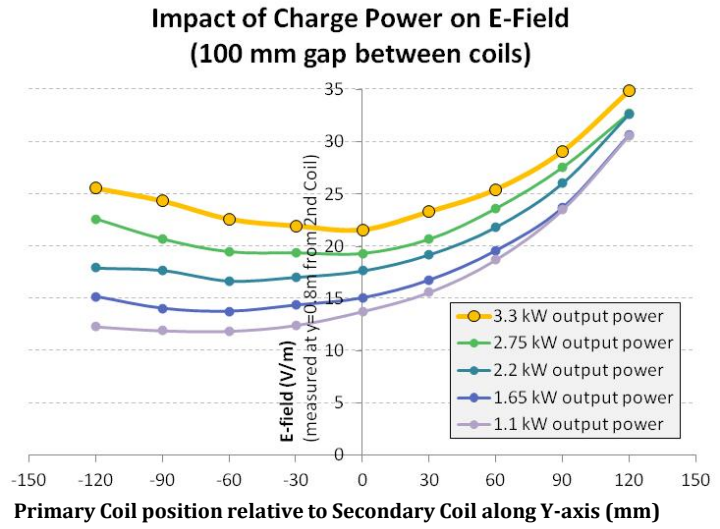


Output Power Impact on System Efficiency and EM Field

- 100mm coil to coil gap
- EM field measured at
  - X=0.0m Y=0.8m
  - Centered vertically in gap (Z=-50mm)







Fact Sheet

Idaho National Laboratory

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy | VEHICLE TECHNOLOGIES PROGRAM

PLUGLESS™ Level 2 EV Charging System (3.3 kW) by Evatran Group Inc.

Results from Full System Testing in a Laboratory environment

Description / Specifications [1]

System Input Voltage operating Voltage	208 to 240	VAC
Circuit Breaker Rating	30	A
Nominal gap between coils	100	mm
Rated maximum power output	3300	watts
Parking Pad (Primary Coil system)		
Shape	Approximately Circular	
Size	559 dia. x 470 long	mm
Vehicle Adapter (Secondary Coil system)		
Shape	Rectangular	
Size	464 long x 525 wide	mm

Measured System Parameters during Laboratory Testing

Input Power Measurements (at 3.3 kW output, 100mm gap)

Input Voltage	208	VAC
Input Current RMS	28	Amps RMS
Power Factor	0.65	
Voltage Total Harmonic Distortion (THD)	4	%
Current Total Harmonic Distortion (THD)	112	%

Wireless Power Transfer Operation

Operating Frequency (kHz)	19.5	kHz

DC Output Measurements (at 3.3 kW output, 100mm gap)

Output Voltage	214	VDC
Output Current	15.4	Amps
Voltage Ripple Factor	0.75	%

Operating Temperatures at 3.3 kW output

Parking Pad: Max observed surface temperature	51	°C
Vehicle Adapter: Max observed surface temperature	47	°C

Laboratory Test Measurement Coordinate System [2]

[1] Manufacturer's Specifications: http://www.pluglesspower.com/wp-content/uploads/2013/06/PluglessL2_Specs.pdf

[2] Test Coordinates System Origin: Center of the Secondary Coil at the Bottom Surface of the Enclosure

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GLESS™ Vehicle Adapter

GLESS™ Control Panel

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Power Electronics

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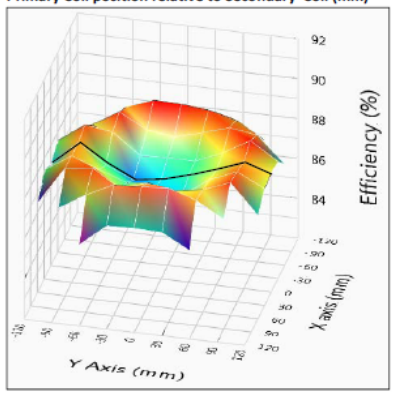
System Efficiency at 100mm gap for 3.3kW output
Primary Coil position relative to Secondary Coil (mm)



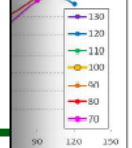
th 100mm gap)

	Primary Coil position relative to Secondary Coil (mm)[2]
88.8%	(-90,-30)
87.0%	(0,0)
86.1%	(120,-60)

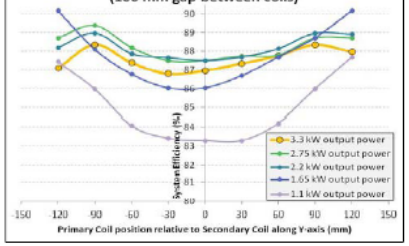
th 110mm gap)

	Primary Coil position relative to Secondary Coil (mm)[2]
89.2%	(-60,30)
88.1%	(0,0)
86.2%	(90,90)

Efficiency



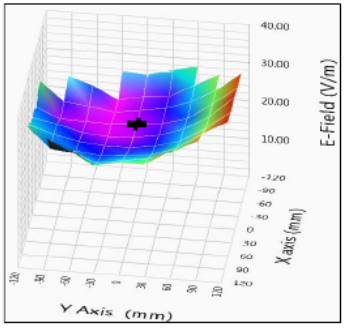
Impact of Charge Power on System Efficiency (100 mm gap between coils)



tric Field

3.3 kW output) for Primary Coil position relative to Secondary Coil

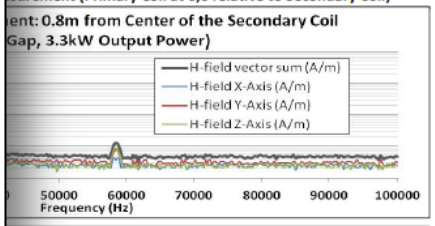
Electric Field (E-field)[3]



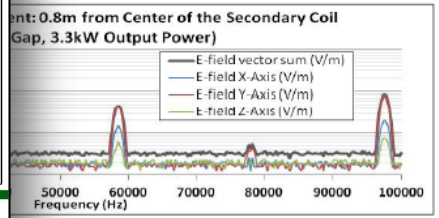
0mm gap)	Primary Coil position relative to Secondary Coil (mm)[2]
21.9	(0,120)
12.9	(0,0)
35.2	(60,120)
22.1	(0,0)

asurement (Primary Coil at 0,0 relative to Secondary Coil)[3]

ent: 0.8m from Center of the Secondary Coil Gap, 3.3kW Output Power)



ent: 0.8m from Center of the Secondary Coil Gap, 3.3kW Output Power)



mm below secondary coil) 0.8m from Secondary Coil Center along Y-axis

http://avt.inel.gov/evse.shtml

Response to Previous Year Reviewer Comments

- Reviewer stated: “The project clearly demonstrated collaboration in all areas including agreements and broad participation for needed partners.”
- The collaborative agreements established in the previous year enabled extensive testing and results publication. Also the results supported standards development also through collaborative efforts.

- Reviewer stated: “Future work was identified for most of the projects as time dependent on others for the evaluations. INL appeared to be ready for evaluations and not the cause for any delays.”
- Due to preparation in the previous year, once charger hardware was received for evaluation by INL, the testing commenced in a timely manner. Analysis was conducted and results were published. Additional testing, much of which was iterative, was in an effort to support test procedure development for wireless charging standards.

Future Work

- Conduct testing of two wireless charging systems from the awardees of the FOA-667 at the beginning of Phase III
- Proposed collaborative testing with Momentum Dynamics
  - Medium Duty electric shuttle bus wireless charger
  - Wireless charger intended for sedan / passenger car
- Conduct testing of production Evatran PLUGLESS system
- Obtain and test other wireless charging systems from other manufacturers in an effort to test a variety of systems of differing design and frequency
- Continue to support SAE J2954 test procedure and standards development

Summary / Comments:

- Completed: INL's laboratory testing of the pre-production PLUGLESS™ Wireless Charging system by Evatran Group Inc.
  - Fact Sheet published
    - **http://avt.inel.gov/evse.shtml**
  - 2014 SAE World Congress paper detailing the test results
    - 2014-01-1824
  - Presentation at "Plug-in 2013" conference
    - http://avt.inel.gov/pdf/phev/WirelessChargingPlugIn2013.pdf
- Results and feedback provides to SAE J2954 wireless charging committee for test procedure development and refinement

Acknowledgement

This work is supported by the U.S. Department of Energy's EERE Vehicle Technologies Program

More Information

http://avt.inl.gov