Idaho National Laboratory

Testing Results: *PLUGLESS*[™] Wireless Charging System by Evatran Group Inc.



www.inl.gov

Jim Francfort December 2013 IWC meeting, Franklin, TN

INL/MIS-13-30727







What is Wireless Charging for Plug-In Vehicles?

- Wireless Power Transfer (WPT) across an air gap
 - Power Electronics convert grid power (60Hz) to higher frequency power
 - Typical operating frequency: 20 kHz to 150 kHz
 - 85 kHz is emerging as the selected frequency by OEM's
 - Coil to Coil coupling via magnetic resonance enables high efficiency power transfer across the air gap
 - Higher frequency power rectified is into DC power to charge the battery





INL Wireless Charging Testing

- <u>Scope</u>: Provide Results from Testing
 - System Efficiency
 - Electric and Magnetic (EM) Field Strength
 - Impact on Grid (power quality, harmonics, etc.)
 - Support SAE J2954 committee
- Factors that impact System Efficiency and EM Field
 - Coil to Coil Position
 - Alignment (X, Y, θ , Tilt)
 - Gap between coils
 - Output Power
 - Temperature (warm-up effects)
- Testing is conducted in conjunction with SAE J2954 guidelines



INL Wireless Charging Test Equipment

- Programmable Loads
 - AC Loads (9.0 kW) Chroma 63804
 - DC loads (58 kW) Chroma 63210
- Hioki 3390 Power Meter
 - 4 channel AC and DC current and voltage
 - Real-time integration for power & energy
- NARDA EHP-200a
 - Electric Field
 - Magnetic Field
- FLIR SC640 Thermal Camera^{T/2}
- Fiberglass channel strut frame with multi-axis positioning table
- CAN communications (as required)
- Custom LabVIEW test control program for data acquisition and test host function to synchronize all test operations









INL Wireless Charging Laboratory Testing





INL Wireless Charger Coil Positioning

- Primary Coil
 - Software position control
 - Ball-screw positioning table with servo motors
 - Χ, Υ, θ
 - Supported by polycarbonate stand-off
 - Increase distance to the metallic positioning table
- Secondary Coil
 - Suspended from fiberglass channel strut frame
 - Manually adjusted
 - Z position (coil to coil Gap)
 - Tilt by differential Z



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



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INL Laboratory Test Setup: PLUGLESS[™] by Evatran

- Three Measurement Nodes
 - AC Grid Input (60 Hz)
 - Control Panel output to Primary Coil (parking pad)
 - DC Vehicle Adaptor output to On-Board Charge Module (OBCM)
 - Secondary coil output was unable to be measured due to sealed vehicle-side enclosure



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INL Laboratory Test Setup

- Measurement orientation
 - Origin:
 - Bottom face the Vehicle Adapter enclosure
 - Center of the Secondary Coil (inside Vehicle Adapter)
 - X: towards front of vehicle
 - Y: towards drivers side
 - Z: up through roof





PLUGLESS[™]:

Driver's Parking Alignment Guide System

- Green arrows on the Control Panel direct driver towards best alignment
- Numbers on control panel indicates alignment "score" (0-99)
- INL's X and Y positioning system origin is very close to the "best alignment" of the PLUGLESS[™] Alignment Guide
 - A few iterations to get to this origin positioning
 - Perhaps markings on case enclosures to aid test labs







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)





Z

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



Definition: System Efficiency

System Efficiency = Energy into PLUGLESS[™] Vehicle Adapter Energy into PLUGLESS[™] Control Panel

Power Flow from Generation to Vehicle Operation

Electricity Generation Electricity Distribution Electricity Step Down Transformer Commercial / Residential Wiring & Receptacle PLUGLESS ™ Control Panel / Power Electronics PLUGLESS ™ Primary Coil PLUGLESS ™ Secondary Coil PLUGLESS ™ Vehicle Adapter / Power Electronics Vehicle On-Board Charge Module (OBCM) Vehicle Wiring / Accessory Loads Vehicle Traction Battery (ESS) Vehicle Propulsion



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 wi	th 100mm gap)
Maximum Efficiency (%)	88.8%
Nominal Efficiency (%)	87.0%
Minimum Efficiency (%)	86.1%



Primary Coil position relative to Secondary Coil (mm) (-90,-30) (0,0) (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)



- 3.3 kW output
- 100mm gap (nominal case)







- 3.3 kW output
- 70mm gap





- 3.3 kW output
- 80mm gap





- 3.3 kW output
- 90mm gap





- 3.3 kW output
- 100mm gap (nominal case)





- 3.3 kW output
- 110mm gap



- 3.3 kW output
- 120mm gap

- 3.3 kW output
- 130mm gap

Coil to Coil Gap Impact on System Efficiency and EM Field (3.3 kW Output Power)

Primary Coil position relative to Secondary Coil along Y-axis (mm)

Primary Coil position relative to Secondary Coil along Y-axis (mm)

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• 3.3 kW output

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

Impact of Coil Gap (mm) on System Efficiency (3.3 kW Output Power)

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)

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

Warm-up (at nominal conditions)

- Does Temperature have an Impact?
- Nominal (3.3 kW, 100 mm gap), Aligned (0,0)
- Test starts (3.3kW) immediately after 208 VAC connected to control panel

AC Input Waveform: Power Factor & Total Harmonic Distortion (THD)

- 0.65 Power Factor (consistent across power, position, and gap variation)
- Input Current THD = 112% (at 3.3 kW output)
- Input Voltage THD = 4% (at 3.3 kW output)

Fact Sheet

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

Next Steps

- Vehicle level testing completed (not yet published)
 - PLUGLESS system
 - Installed on Chevy Volt
 - Outdoor testing (asphalt parking lot)
 - Same measurement equipment as in lab (Hioki, NARDA, etc.)
 - Correlate to specific test points conducted in laboratory
- Conduct debris testing (in progress)
 - After INL safety review approval (since debris will get hot = potential for fire)
 - Empty soda can, paper clips, CD, rebar, coins, paper clip, etc.
 - At various distance from wireless charger operating at nominal condition (3.3 kW, 100mm gap, various coil misalignment)

Summary / Comments:

- INL's laboratory testing of the PLUGLESS[™] Wireless Charging system by Evatran Group Inc. is complete
 - System Efficiency and EM field measurement impact from
 - Coil to Coil Position
 - Gap
 - Alignment Offset
 - Output Power
 - EM field meter measurement location
- Fact Sheet has been published

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

Acknowledgement

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

More Information

http://avt.inl.gov