Wireless & Conductive Charging Testing to Support Code & Standards

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Overview

Timeline

FY15

- Wireless charging test results to support test procedure development
- Initiate support of ENERGY STAR EVSE test method development

FY16

- Support SAE J2954 test procedure development for Interoperability testing
- Bench test setup for SAE J2954
- Evaluate FOA-667 wireless chargers
- Finalized test method development for EnergyStar EVSE evaluation

Barriers

- Lack of common test procedures
- Compatibility / Interoperability and safety issues for wireless chargers
- Potential cyber security vulnerabilities
- Charging systems power quality impacts on the grid
- Lack of published results / data from advanced charging systems

Budget

- FY15: $ 630k
- FY16: $ 250k

Partners

- OEMs and Industry partners
  - SAE J2954
  - SAE J2894
  - Oak Ridge National Lab
  - Hyundai, Mojo Mobility
- EPA Energy Star

Objective / Relevance

- INL provides independent testing and evaluation results for:
  - Wireless charging systems
  - Conductive electric vehicle supply equipment (EVSE)
  - On-board charging systems
- Provide DOE with feedback for technology development investments and Funding Opportunity Announcements
- Support industry's development and harmonization of wireless and conductive charging codes and standards

- Evaluation of Charging Systems and Infrastructure is relevant:
  - Characterize impact and interaction with the grid
  - Standardization reduces risks and costs of new technologies
  - Increased EV adoption through consumer awareness

Milestones

- Testing of the two wireless charging systems from FOA-667
  - Efficiency, power quality, and EM-field results as impacted by coil alignment, coil gap, input voltage, and charge rate
    - completed Jan 2016: ORNL / Toyota / Evatran / ICAR wireless charger
    - In progress: Hyundai / Mojo Mobility wireless charger (April / May 2016)

- Support SAE J2954 (wireless charging) development
  - INL provided specific test setup and procedure details
  - INL will conduct up coming J2954 Interoperability testing
    - Test Plan finalized as of April 11, 2016

- Finalized conductive EVSE test procedures for ENERGY STAR

- Supported SAE J2894 with published test results
  - Power quality test results from five PEV on-board charging systems
  - In-rush current measurement from vehicle charging systems

Approach:
INL's Electric Vehicle Infrastructure Laboratory

Evaluate Conductive and Wireless Charging Systems

- System Efficiency
- EM-field emissions
- Power quality
  - Total harmonic distortion
  - Power factor
  - Transient response
- Cyber security assessment
  - Communications security
    - Wired and wireless
  - Software and firmware

- Wide range of input power
  - 120 VAC, 208 / 240 VAC, 480 VAC 3ϕ
  - 400 kVA total capability
- Grid Emulator (60 kVA) enables the evaluation of charging infrastructure performance and response during transient grid events

Approach: INL's Wireless Charging Testing and Evaluation

Vehicle testing

- Wireless charger evaluate as integrated into a vehicle
- Non-metallic vehicle ramps used to elevate vehicle to provide necessary space for the coil positioning system

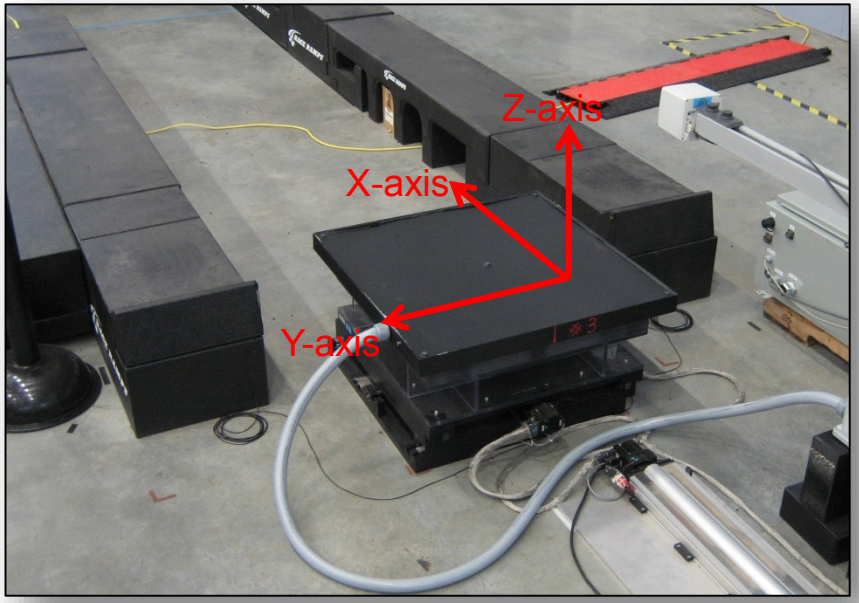
Bench sub-system testing

- Fiberglass frame and fasteners supports the vehicle side coil and power electronics
- Vehicle emulation modules
  - Battery emulator, communications

Approach: Wireless Charger Coil Positioning System

Coil positioning system for primary coil (ground assembly)

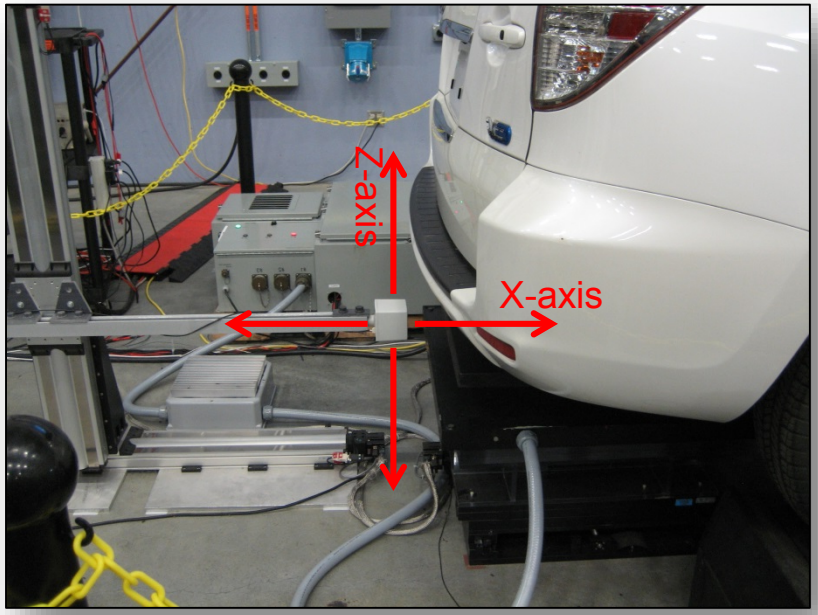
- Servo-motor driven
- Enables accurate coil misalignment
  - Move ground coil assembly with respect to vehicle coil
  - Vehicle remains stationary on non-metallic ramps



Approach:
Magnetic and Electric Field scan around vehicle

EM-field meter positioning device

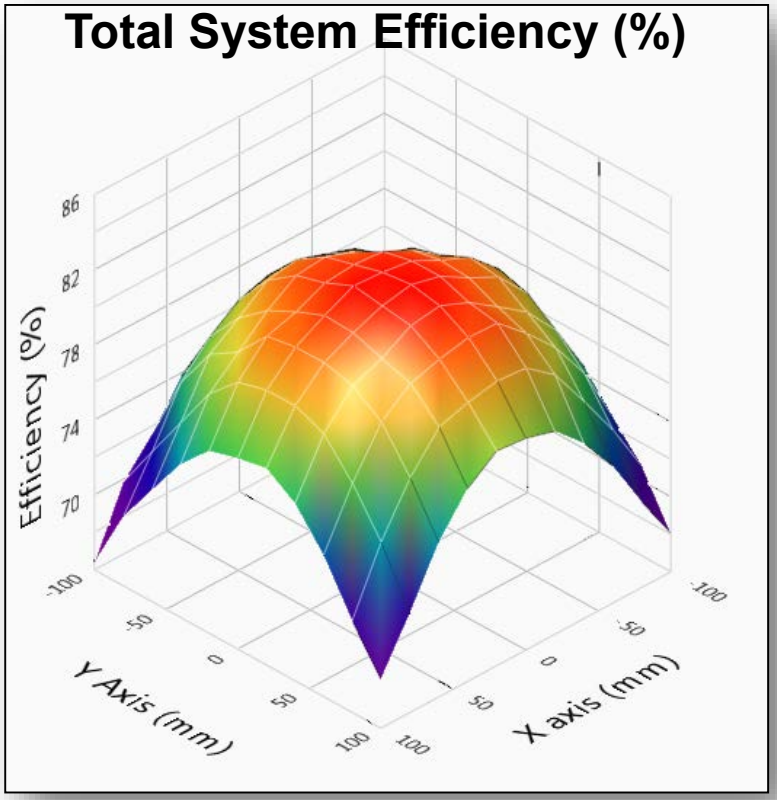
- Servo-motor driven
- Accurate positioning of the EM-field sensor
  - Enables quasi-static EM-field scan in the XZ plane



Accomplishments: ORNL Wireless Charger Performance Results

ORNL Wireless charging system (FOA-667) was evaluated:

- Efficiency
  - System Efficiency
  - Sub-system Efficiencies
- Power quality
  - Power Factor
  - Harmonic Distortion
- Electromagnetic field around vehicle
- Across a wide range of
  - X & Y coil misalignment
  - Z coil to coil gap
  - Input voltage (208V to 240V)
  - Output voltage (275V to 375V)
  - Output power (up to 7.0 kW)

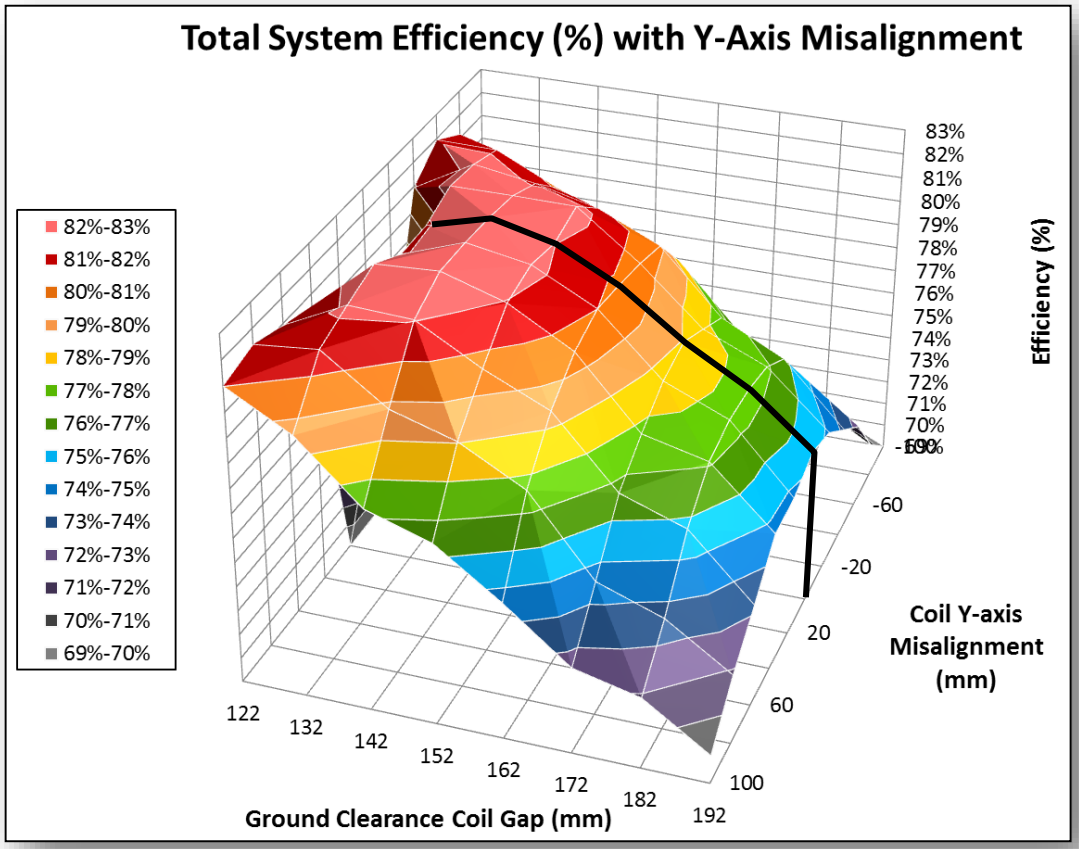


Max. = 82.2 %

http://avt.inel.gov/pdf/presentations/ORNLWPTSAESymoisuym2016.pdf

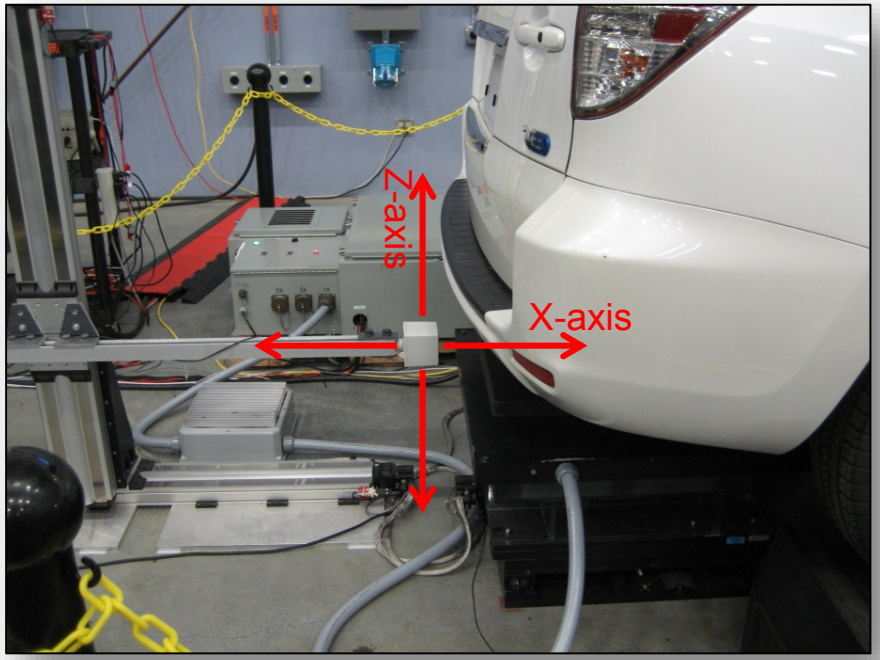
System Efficiency: Impact of Gap and Misalignment

- Gap and Misalignment have significant impact on system efficiency
- Designed ground clearance: 152mm
  - 82% efficient when aligned
- Misalignment of 100mm
  - 6% efficiency decrease
    - 82% to 76%
- Increase in gap by 40mm
  - 7% efficiency decrease
    - 82% to 75%



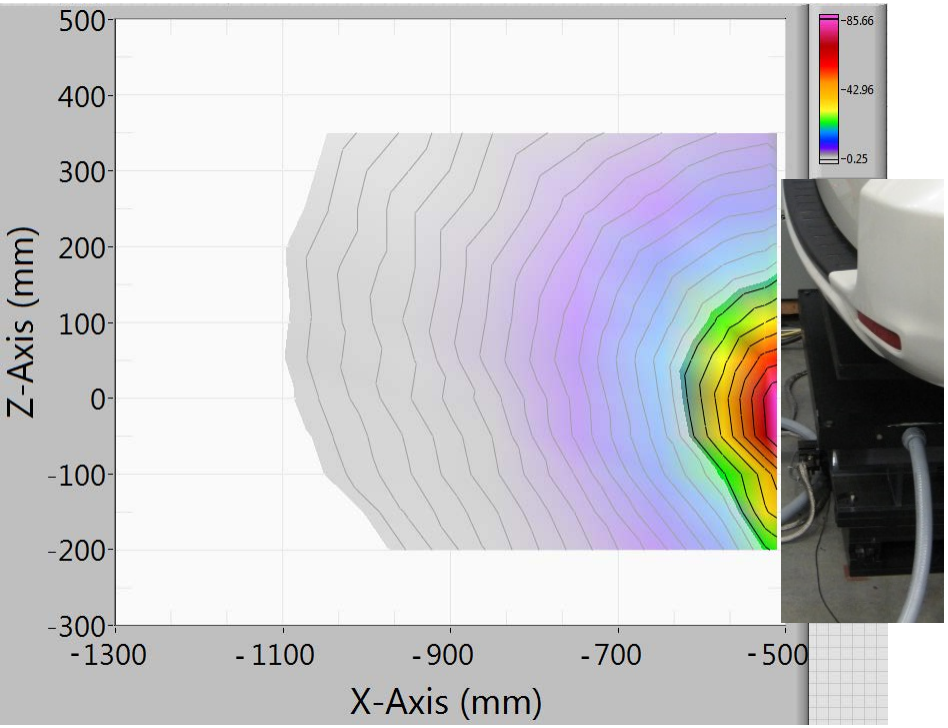
EM-field Scan in X, Z plane near rear bumper

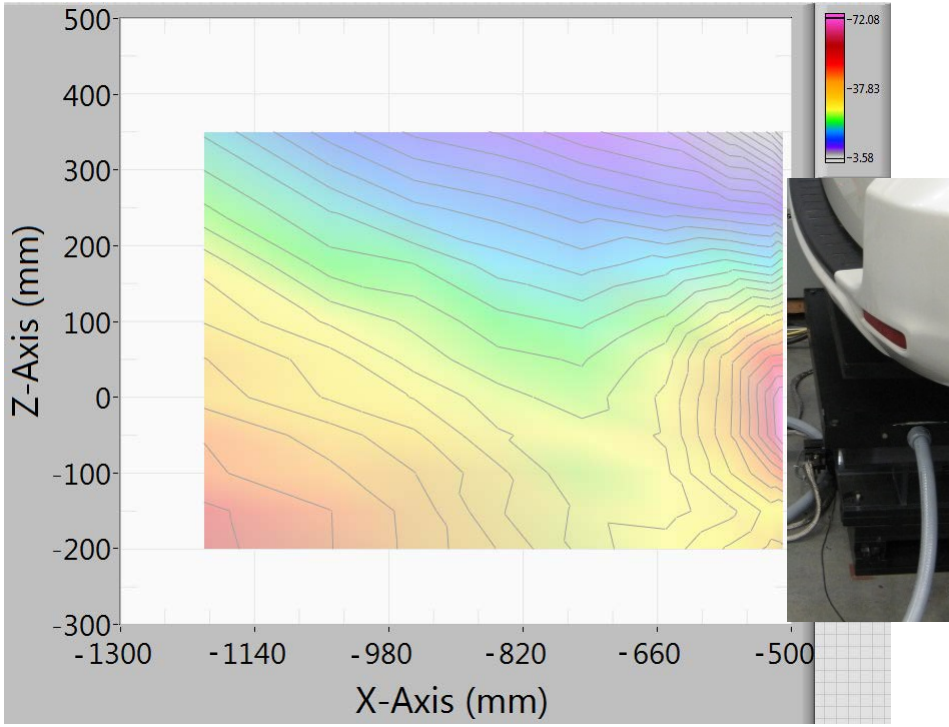
- Coils Aligned (0,0)
- Full power: 6600 watts output
- Input voltage: 240 V RMS
- Output Voltage: 366 VDC



Magnetic and Electric Field at 132mm coil gap

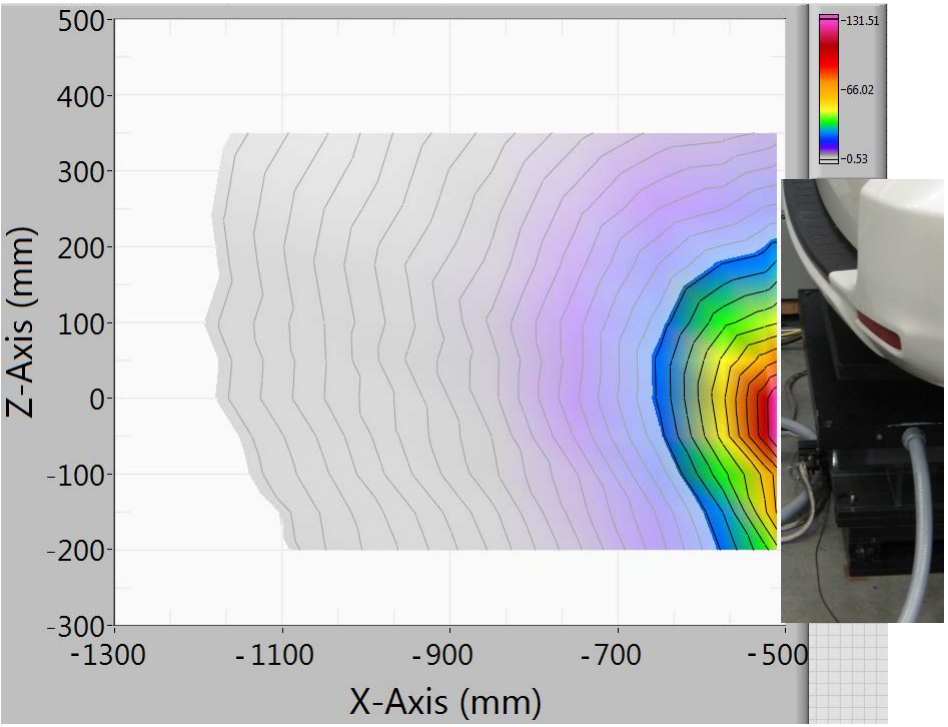
- Bright color area is above ICNIRP 2010 levels (general public exposure)
- Magnetic field (A/m)
  - Large area near bumper at ankle height shows peak of 85.7 A/m
- Electric field (V/m)
  - All areas measured around rear bumper are below ICNIRP 2010

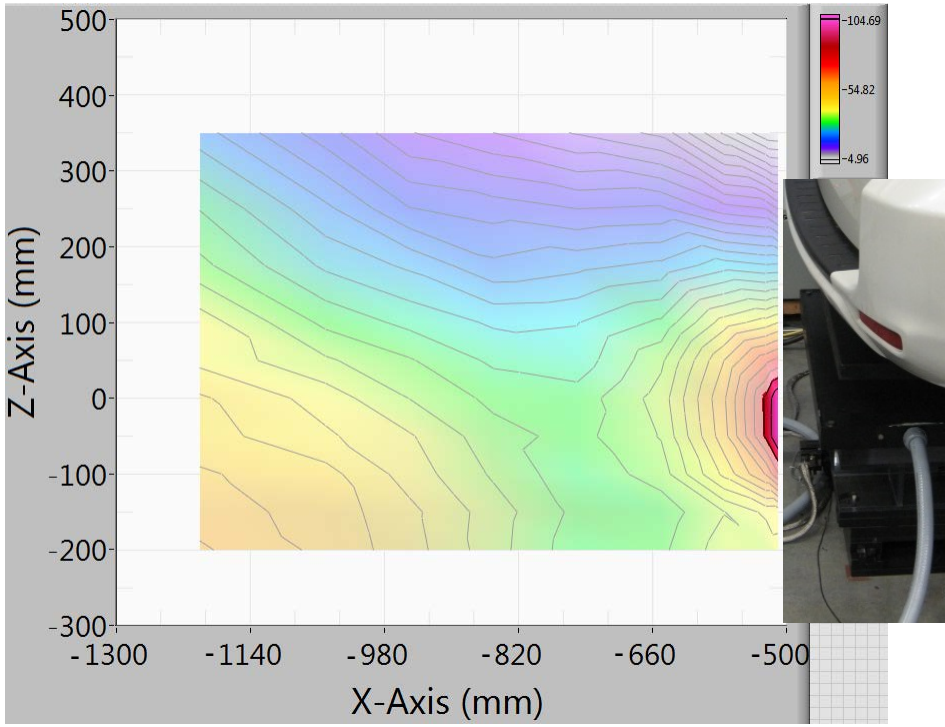




Magnetic and Electric Field at 152mm coil gap

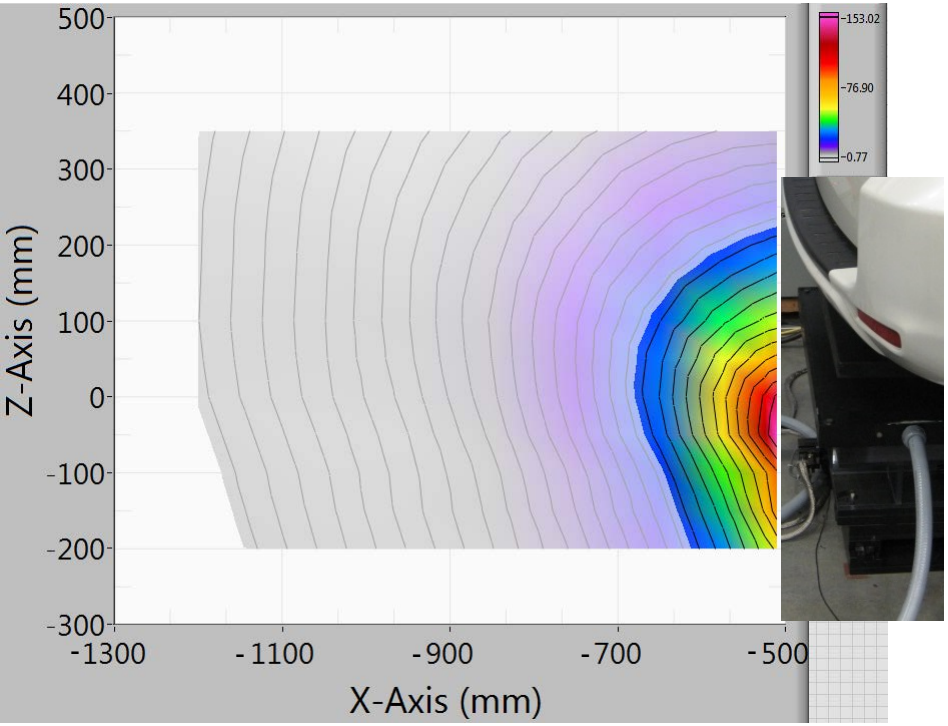
- Bright color area is above ICNIRP 2010 levels (general public exposure)
- Magnetic field (A/m)
  - Large area near bumper at ankle height shows peak of 132 A/m
- Electric field (V/m)
  - Small area near bumper at ankle height shows peak of 105 V/m

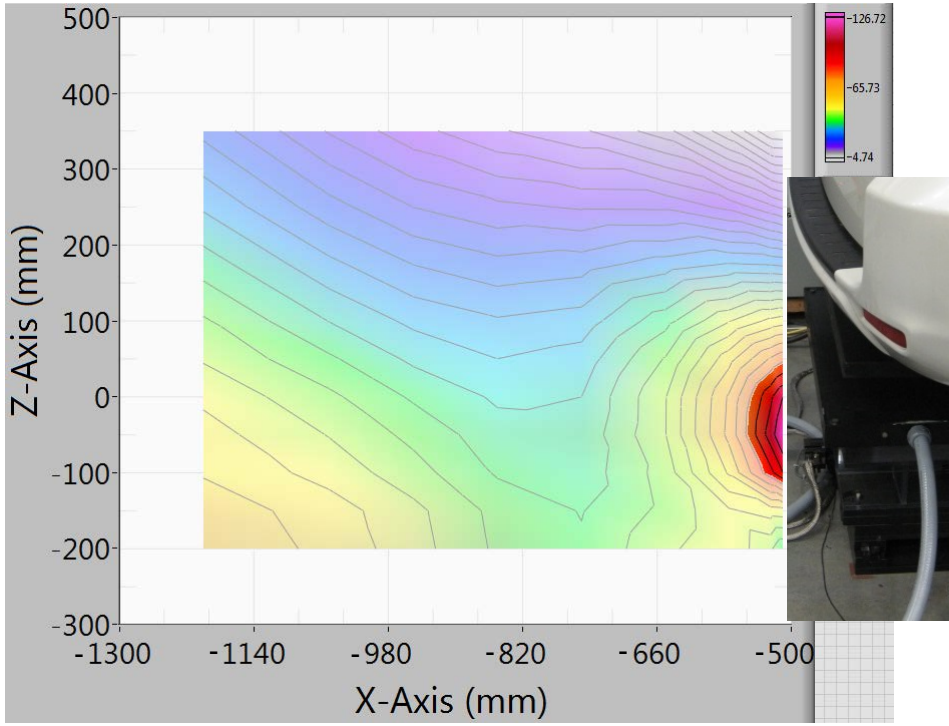




Magnetic and Electric Field at 172mm coil gap

- Bright color area is above ICNIRP 2010 levels (general public exposure)
- Magnetic field (A/m)
  - Large area near bumper at ankle height shows peak of 153 A/m
- Electric field (V/m)
  - Small area near bumper at ankle height shows peak of 127 V/m





Accomplishments: Hyundai / Mojo Mobility Wireless Charger (FOA-667) Testing and Evaluation

INL will conduct testing and evaluation in April and May 2016:

- Efficiency
  - System Efficiency
  - Sub-system Efficiencies
- Power quality
  - Power Factor
  - Harmonic Distortion
- Electromagnetic field
- Across a wide range of:
  - X & Y coil misalignment
  - Z coil to coil gap
  - Output voltage
  - Output power

Accomplishments: SAE J2954 Test Procedure and Test Setup

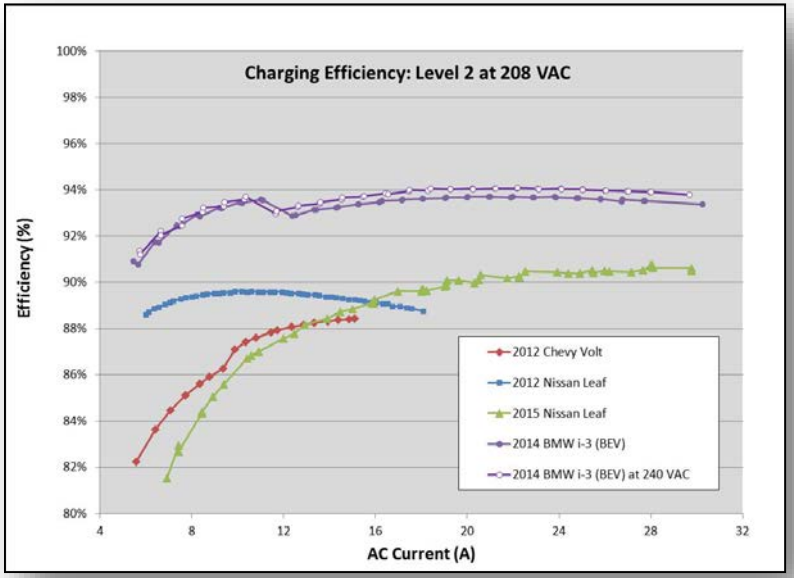
- INL will be conducting the interoperability testing of eight wireless charging systems (Summer 2016)
  - Toyota
  - Nissan / WiTricity
  - Daimler / Jaguar Land Rover / Qualcomm
- SAE J2954 test procedure was completed with significant input from INL testing experience
  - Evaluate efficiency, power quality, EM-field
  - Across a wide range of coil misalignment, coil gap, charger power level, and output voltage
- INL prepared measurement equipment
  - Bench test setup with standardized
    - steel vehicle mimic plate
    - aluminum shield plate

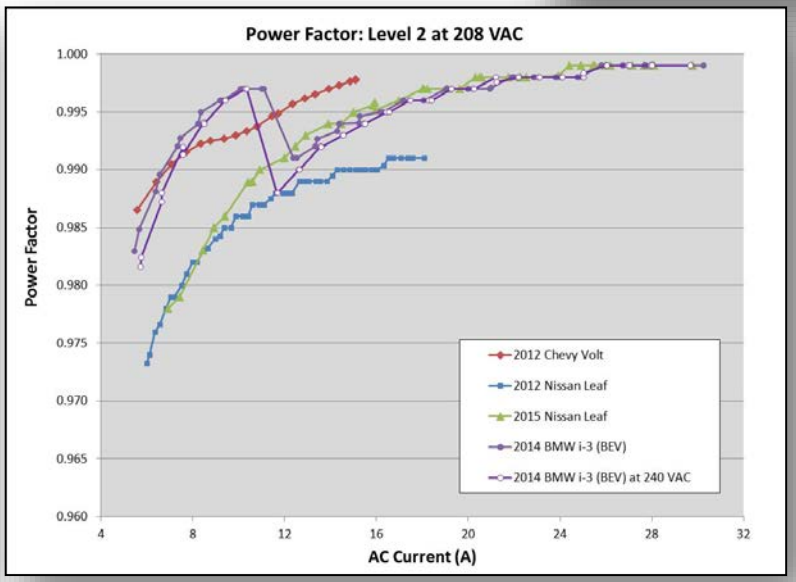
Accomplishments: SAE J2894 Power Quality

Power Quality of On-Board Charger

- 2012 Chevrolet Volt
- 2012 Nissan Leaf
- 2015 Nissan Leaf
- 2014 BMW I3
- 2015 Mercedes-Benz B-Class Electric

Results support SAE J2894 development





http://avt.inel.gov/pdf/EREV/SteadyStateVehicleChargingFactSheet2012Volt.pdf

Accomplishments: ENERGY STAR Conductive EVSE test method

Finalized Test Method document created for EVSE testing

- Definitions
- Test equipment requirements
- Test procedures
  - Standby power consumption
  - Power consumption during charging

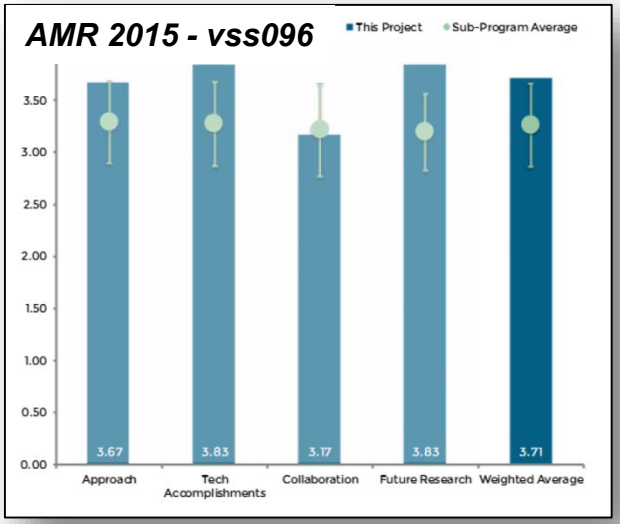
EVSE test results provided to EnergyStar

- To support performance ratings development
- To benchmark performance of current technology

Response to Previous Year Reviewer Comments

Reviewer: "...establish stronger ties / collaboration"

INL has improved collaboration with SAE J2954 team.



Reviewer: "…are any plans to evaluate the charger being used in the Hyundai (vehicle) ..."

In April 2016, INL is evaluating the wireless charging system from Hyundai / Mojo Mobility for the FOA-667. INL is evaluating the system for efficiency, power quality, and EM-field across a wide range of XY coil misalignment, Z coil gap, and output (battery) voltage.

Reviewer: "The reviewer would like to see, as part of this program, well defined, and documented, repeatable test procedures for the charging procedures. "

INL supports test procedure development for SAE J2954 for wireless charging evaluation, SAE J2894 for charging system power quality, and ENERGY STAR for EVSE evaluation. These procedures are developed, refined, and validated from testing results and contributions from INL.

Collaboration with Others

SAE J2954

- Collaborative support of test procedure development through testing and evaluation
- INL will conduct wireless charging interoperability testing of systems from:
  - Toyota
  - Nissan / WiTricity
  - Daimler / Jaguar Land Rover / Qualcomm

ENERGY STAR

- INL is supported creation of EVSE test method document

Independent evaluation of wireless charging system

- ORNL / Toyota / Evatran / ICAR
- Hyundai / Mojo Mobility

Future Work

- Test and evaluate wireless charging systems as available
- Continue to support SAE J2954 test procedure and standards development through testing and evaluation
  - INL will conduct wireless charging interoperability testing of systems from:
    - Toyota
    - Nissan / WiTricity
    - Daimler / Jaguar Land Rover / Qualcomm
    - Results will enable SAE J2954 to determine a reference standard coil design
- Continue to support SAE J2894 development through test results charging systems
  - Power Quality
  - Transient response

Summary:

Completed:

- Evaluation of the system performance of the ORNL / Toyota / Evatran / ICAR wireless charger (FOA-667)
- INL provided specific test setup details for both vehicle and bench test setup to SAE J2954 draft document (TIR)
- Published power quality results from five on-board vehicle charging systems to support SAE J2894
- ENERGY STAR finalized the EVSE test methods document with significant input from INL

In Progress:

- Evaluation of the Hyundai / Mojo Mobility wireless charger (FOA-667)
- Conduct interoperability testing and evaluation on eight wireless charging system to support SAE J2954 development

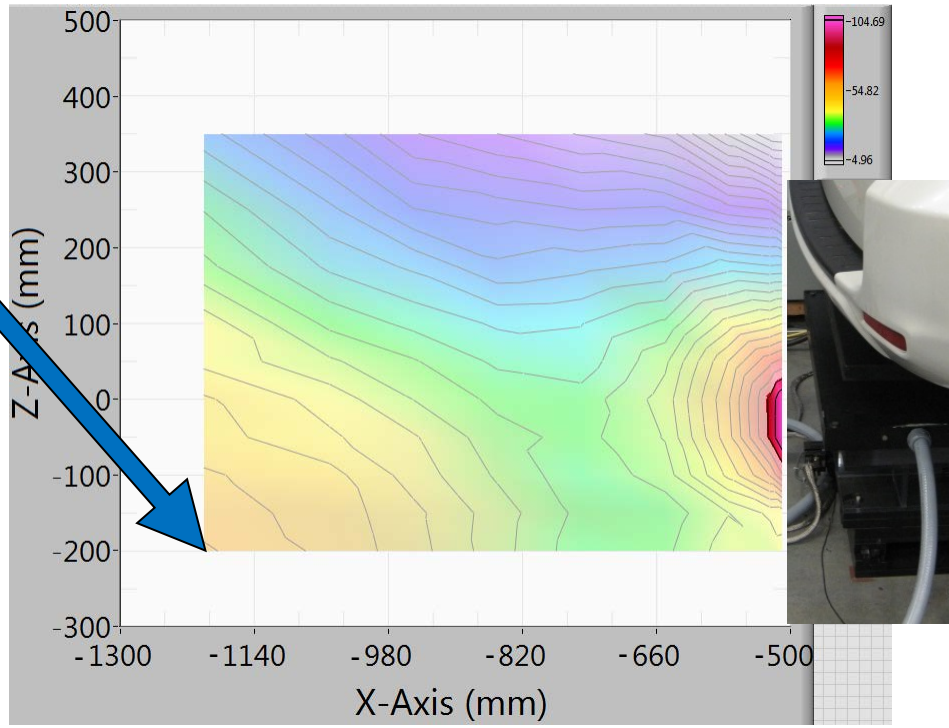
Technical Back-up Slides

Magnetic and Electric Field at 152mm coil gap

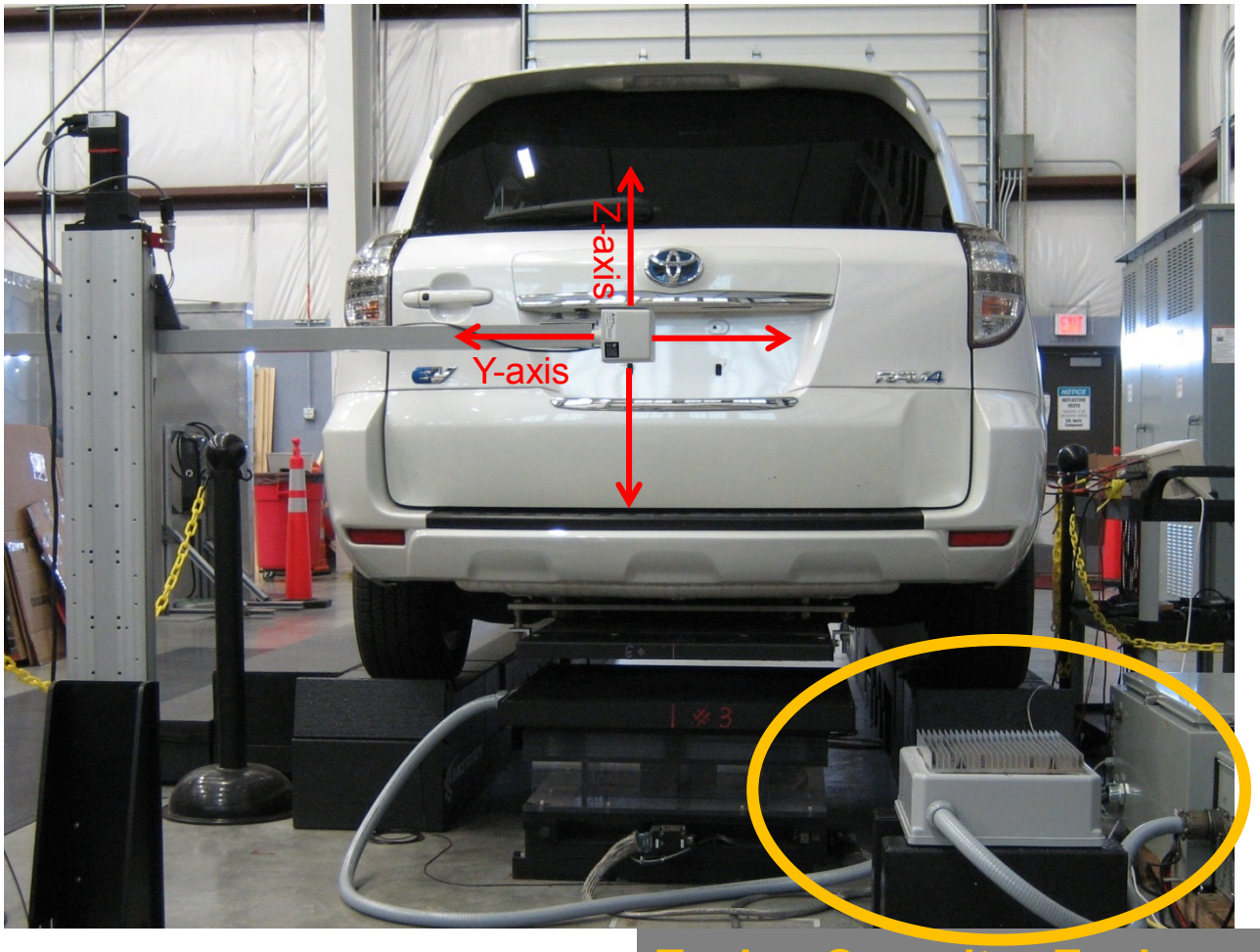
What is the additional Electric field approximately 1.2m from the coil center?

- Approx. 60 V/m

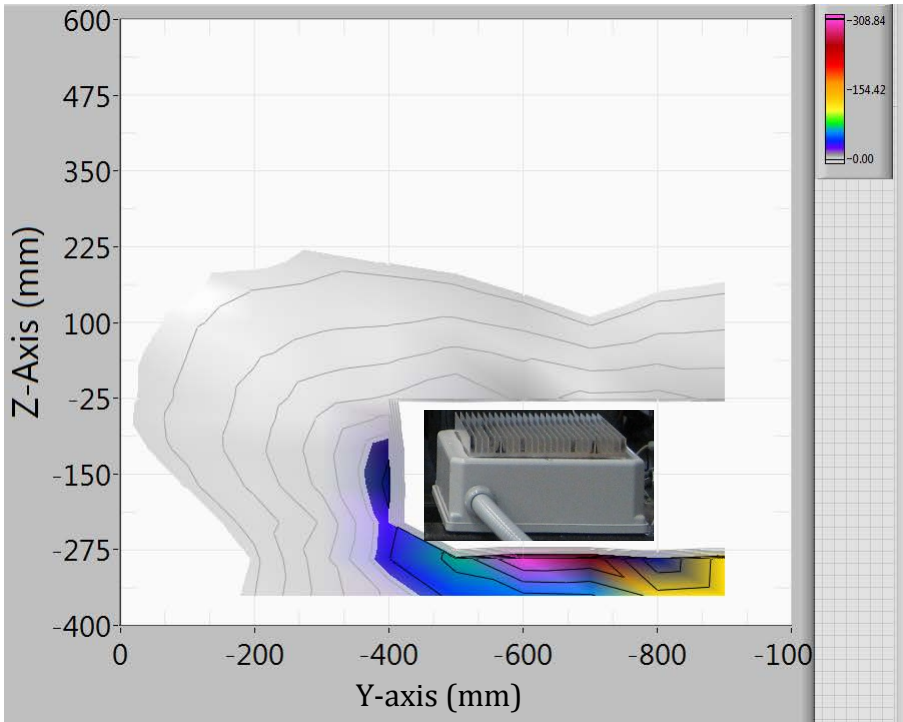
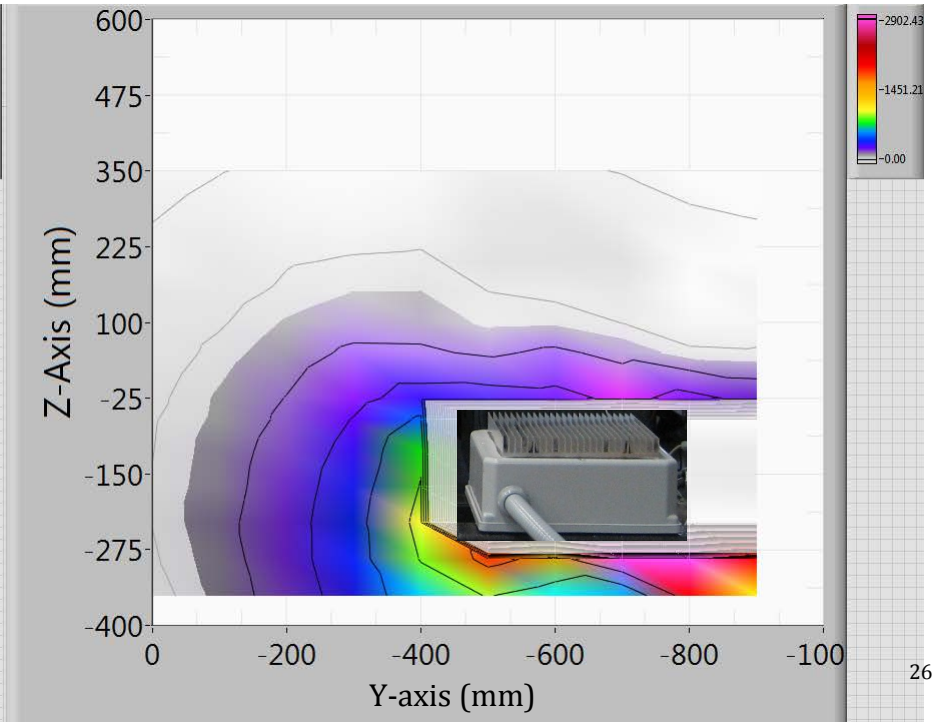
This is EM-field generated from the tuning capacitor enclosure between the GSU and the Primary coil



EM-Field near Tuning Capacitor Enclosure
at 152mm ground clearance coil gap



Tuning Capacitor Enclosure

EM-Field near Tuning Capacitor Enclosure
at 152mm ground clearance coil gap

- Bright color area is above ICNIRP 2010 levels (general public exposure)
- Magnetic field (A/m)
  - Shows peak under the enclosure of 309 A/m
- Electric field (V/m)
  - Shows peak under the enclosure of 2,902 V/m