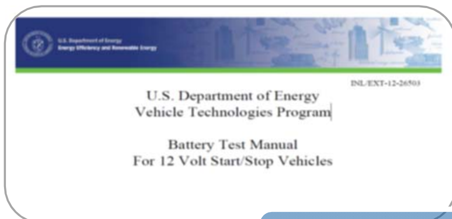
INL's Electric Vehicle Charging Infrastructure Laboratory


U.S. Department of Energy
Vehicle Technologies Program

Battery Test Manual
For 12 Volt Start/Stop Vehicles

Protocols & Procedures

Technology Assessment

Data Analysis

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Core Capabilities

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Electric Vehicle Infrastructure Lab

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Purpose: Electric Vehicle Infrastructure (EVI) Lab

- Evaluate electric vehicle charging infrastructure
  - Independent evaluation of vehicle charging system
    - Efficiency, and Power Quality at various power levels
    - Additionally for wireless charging: EM-field safety and coil alignment and coil gap impact
  - Evaluate cyber security vulnerabilities of charging systems
  - Evaluate and develop EV integration with renewable resources in both distributed and micro-grid environments
- EVI lab supports codes and standards development
  - SAE
    - Wireless Charging (J2954)
    - Charger Power Quality (J2894)
  - EnergyStar ratings for conductive EVSE

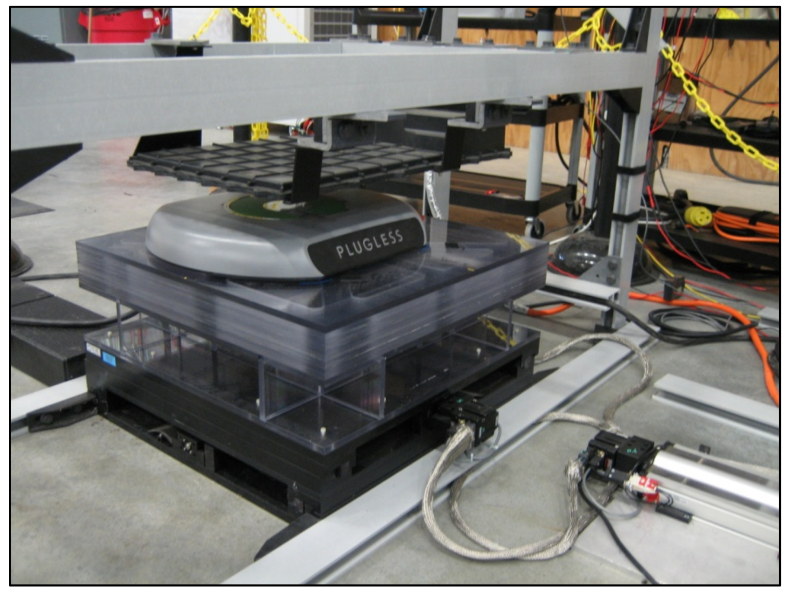
Facility testing capabilities

- Wide range of facility input power (total of 400 kVA)
  - Residential power: 120 / 240 VAC 1ϕ
  - Commercial power: 208 / 480 VAC 3ϕ
- Vehicle emulator (for bench tests)
- Multiple test vehicles from various manufacturers
- Laboratory measurement equipment (Electrical power, EM-field, IR temperature)

Wireless Charging: Evaluation and Codes & Standards Support

INL Wireless charging testing and evaluation

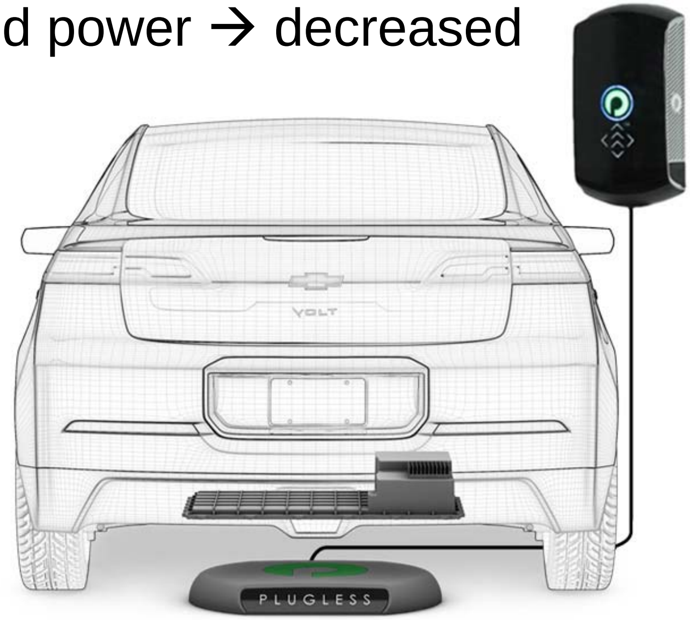
- On-board vehicle testing
- Standalone sub-system testing (bench test)
- Directly supports SAE J2954 test procedure development, EM-field evaluation, and interoperability evaluation
- INL test setup adopted in the current draft of SAE J2954 TIR



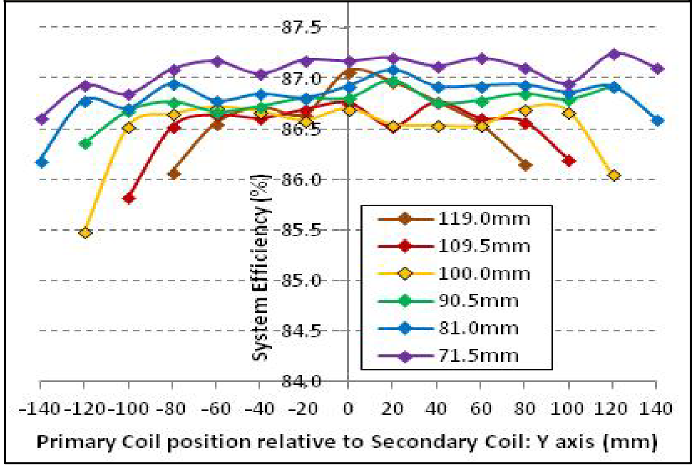
INL Test Results example: Efficiency

Evatran PLUGLESS wireless charger

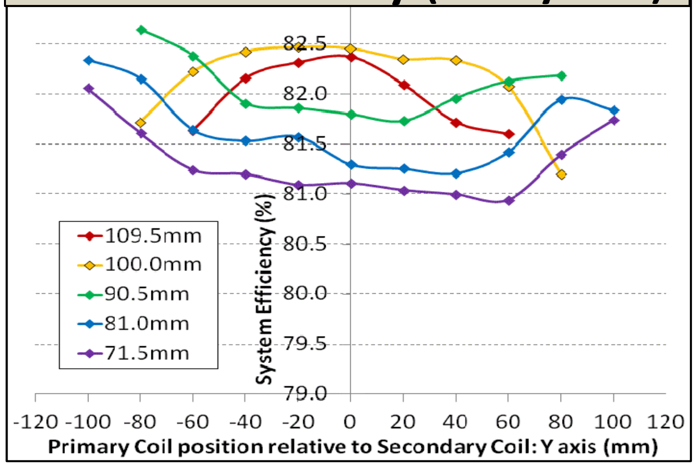
- Efficiency varies with coil gap and misalignment
- Significant differences between on-board and bench testing
  - Due to steel vehicle chassis absorbing electromagnetic field
- Output power also has efficiency effects
  - Decreased power → decreased efficiency



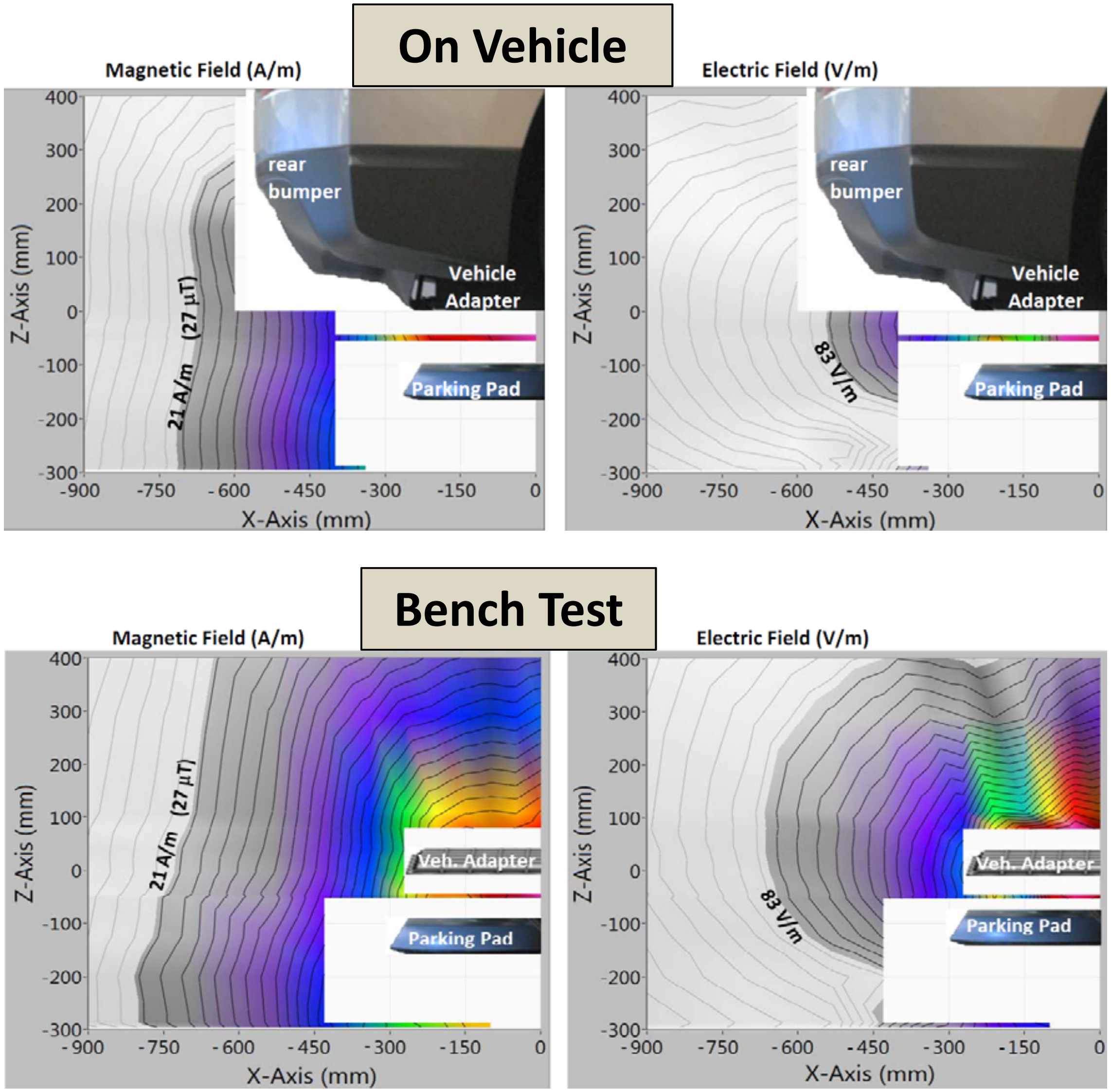
Bench Test Efficiency



Vehicle Efficiency (Chevy Volt)

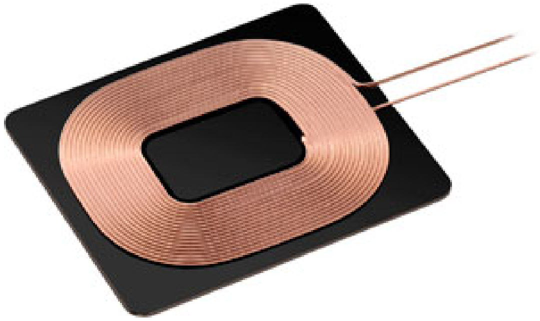


INL Test Results example: EM-field around vehicle



Upcoming Wireless Charging Testing

- U.S. DOE FOA-667 evaluation of vehicle WPT system
  - ORNL, Toyota, Evatran collaboration
    - RAV4 EV with prototype circular topology WPT
    - Input 240 VAC, 50 A
  - Hyundai, Mojo Mobility collaboration
    - Kia Soul EV with prototype circular topology WPT
    - Input 240 VAC, 100 A
  - Three SAE J2954 prototype master / reference coil systems for interoperability evaluation and document requirements refinement
    - WPT1 / Z1-Z2 circular coil topology
      - *3.7 kW, 100-210mm gap*
    - WPT2 / Z2-Z3 circular coil topology
      - *7.7 kW, 140-250mm gap*
    - WPT2 / Z1-Z3 Double "D" coil topology
      - *7.7 kW, 100-250mm gap*



Conductive Charging: Evaluation and Test Procedure Development

Conductive EVSE test procedures for Energy Star

- Test Methods document created for Level 1 and Level 2 EVSE
  - Definitions
  - Test equipment requirements
  - Test procedures and measurements
    - Standby power consumption
    - Power loss during charging
- Ratings recommendations for EVSE with additional features
  - EVSE rated maximum current
  - Cord length
  - Status lights
  - Smart Grid communications
  - Touch screen interface
  - Active brightness control

ENERGY STAR

Evaluation of 4 smart grid capable EVSE

- Four U.S. DOE funded awardees developed EVSE with smart grid communication capabilities
  - Commercial EVSE: GE, Eaton
  - Residential EVSE: Siemens, Delta

- Final deliverable EVSE were evaluated by INL
  - Functionality
  - Stand by power consumption
  - Losses during charging

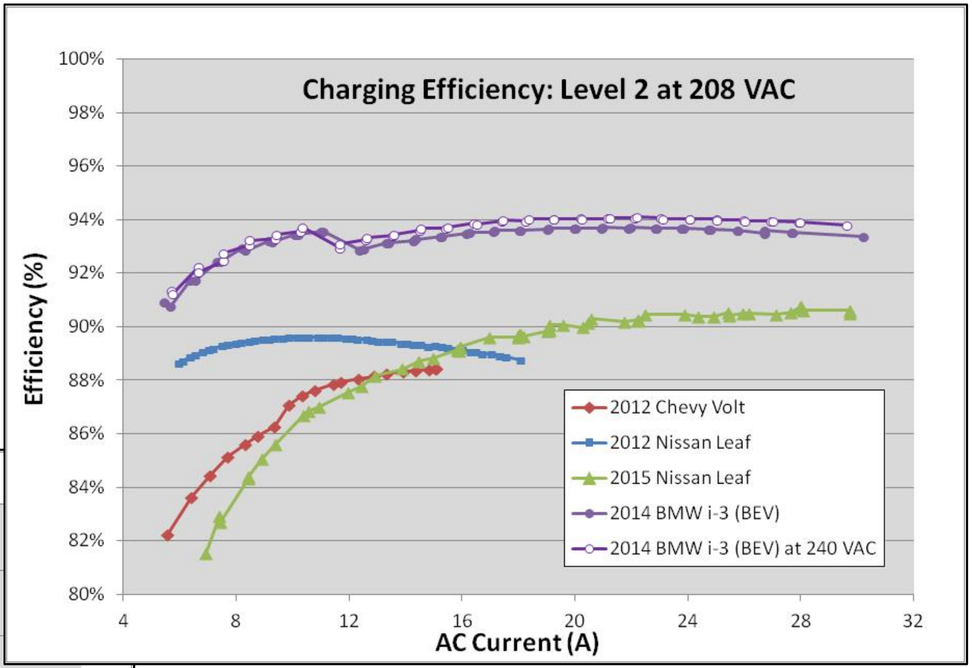
- Cyber Security Vulnerability assessment
  - Physical security
  - Communications security
    - wired and wireless
  - Software and firmware assessment

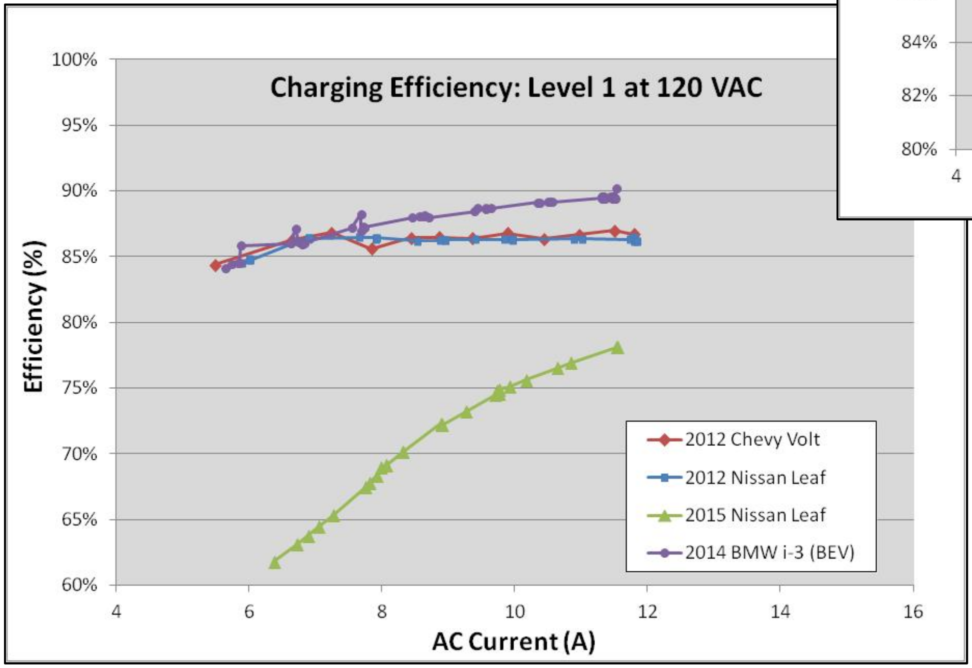
On-board charger power quality

- With smart grid communication, plug-in electric vehicles can be controllable loads on the grid
- Vehicle response must be understood
  - Power Quality (efficiency, power factor, total harmonic distortion)
  - Dynamic characteristics (response to voltage sag, swell, noise, etc.)
- INL supports SAE J2894 development
- INL characterized the on-board charger for several vehicles
  - 2012 Chevrolet Volt (3.3 kW charger)
  - 2012 Nissan Leaf (3.3 kW charger)
  - 2015 Nissan Leaf (6.6 kW charger)
  - 2014 BMW i3 (7.2 kW charger)
  - more planned in the near future

INL Test results of On-Board Charger: Efficiency

- Variation in charge efficiency
  - Vehicle models
  - Charge power level
  - Level 1 vs. Level 2





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EVI Lab Coordination in other Areas of Research

Cyber Security Evaluation of Charging Infrastructure

- DC Fast Charger cyber security vulnerability assessment
  - CHAdeMO using Nissan Leaf
  - CCS using Chevy Spark

- Evaluate cyber security
  - Vulnerability in connection between DCFC to vehicle
    - Protocols
    - communication
  - DCFC to back office
    - includes data, billing, energy management, etc.
  - Vehicle robustness to attack

Vehicle Integration with Renewable Resources

- RTDS
  - High speed control and communication between INL and NREL
- Renewable resources
  - wind, solar, etc.
- Electric vehicles
- Micro-grid
- Supports grid modernization
- Coordinated control system
- Cyber security

Charging Infrastructure Evaluation with RTDS

- Evaluate charging infrastructure using Grid Emulator
  - Variable AC power supply
    - 1ϕ or 3ϕ phase
    - 100 VAC to 520 VAC
    - Bi-directional
    - Dynamic grid event emulation
      - sag, swell, step, pulse, harmonics, etc.
- Real Time Digital Simulation
  - Hardware in the loop
  - Integration with renewable resources
  - Real time connection between RTDS at INL and NREL

Summary

INL's EVI lab is the U.S. DOE core capability for evaluating wireless and conductive charging systems

- Benchmark advanced technologies
  - Charging system performance and safety
- Support codes and standards development
  - SAE J2954, J2894, and EPA Energy Star
- Cyber Security vulnerability evaluation
- Develop and evaluate vehicle integration with renewable resources and other grid modernization efforts