INL Efficiency and Security Testing of EVSE, DC Fast Chargers, and Wireless Charging Systems

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Advanced Vehicle Testing Activity (AVTA)

May 14, 2013

Project ID VSS096

2013 DOE Vehicle Technologies Program Annual Merit Review

INL/MIS-13-28724

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Overview

Timeline

- FY12 – Identify industry test procedures, test equipment and technology testing candidates. Initiate NDAs, testing to demonstrate efficiency and security issues, and develop benchmark results
- FY13 – Continue developing NDAs, testing, and results reporting

Budget

- FY12 – $ 750k
- FY13 – $ 500k

Barriers

- Efficiencies of various charging technologies are publicly unknown and often measured differently
- Wireless efficiency predictions made without universal test methods and results
- Compatibility and safety issues and potential cyber security vulnerabilities

Partners

- Idaho National Laboratory (INL)
- DOE Office of Electricity Delivery and Energy Reliability (OE)
- DOE Office of Energy Efficiency and Renewable Energy (EERE)
- Industry partners: Delta, Eaton, General Electric, Siemens, Evatran, Hyundai, Mojo, ORNL, Consumers Energy, ECOtality, SMUD, Nissan, Aerovironment, NYC Taxi & Limousine Commission, OEMs, SAE, UL, NYSERDA, NYPA, Port Authority NY/NJ, and Energetics

Objective / Relevance

- **Provide an unbiased and independent testing platform for:**
  - **Conductive electric vehicle supply equipment (EVSE)**
  - **Conductive DC Fast Chargers (DCFC)**
  - **Wireless charging systems (WCS)**
- **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, SAE's and UL's development of wireless charging standards and test procedures**
- **Demonstrate real-world use with common efficiency measurements of EVSE, DCFC and WCS technologies**

Objective / Relevance – cont’d

- INL’s efficiency and security testing provides answers to several questions about charging systems
  - Provides a level playing field for discussions regarding different charging technologies
  - The conductive and wireless charging industries quote various efficiencies but the efficiencies are often measured at different system nodes
  - Identify implementation issues even when EVSE , DCFC, and vehicles are independently compliant with J1772
  - Identify potential DC Fast Charge impacts on battery life

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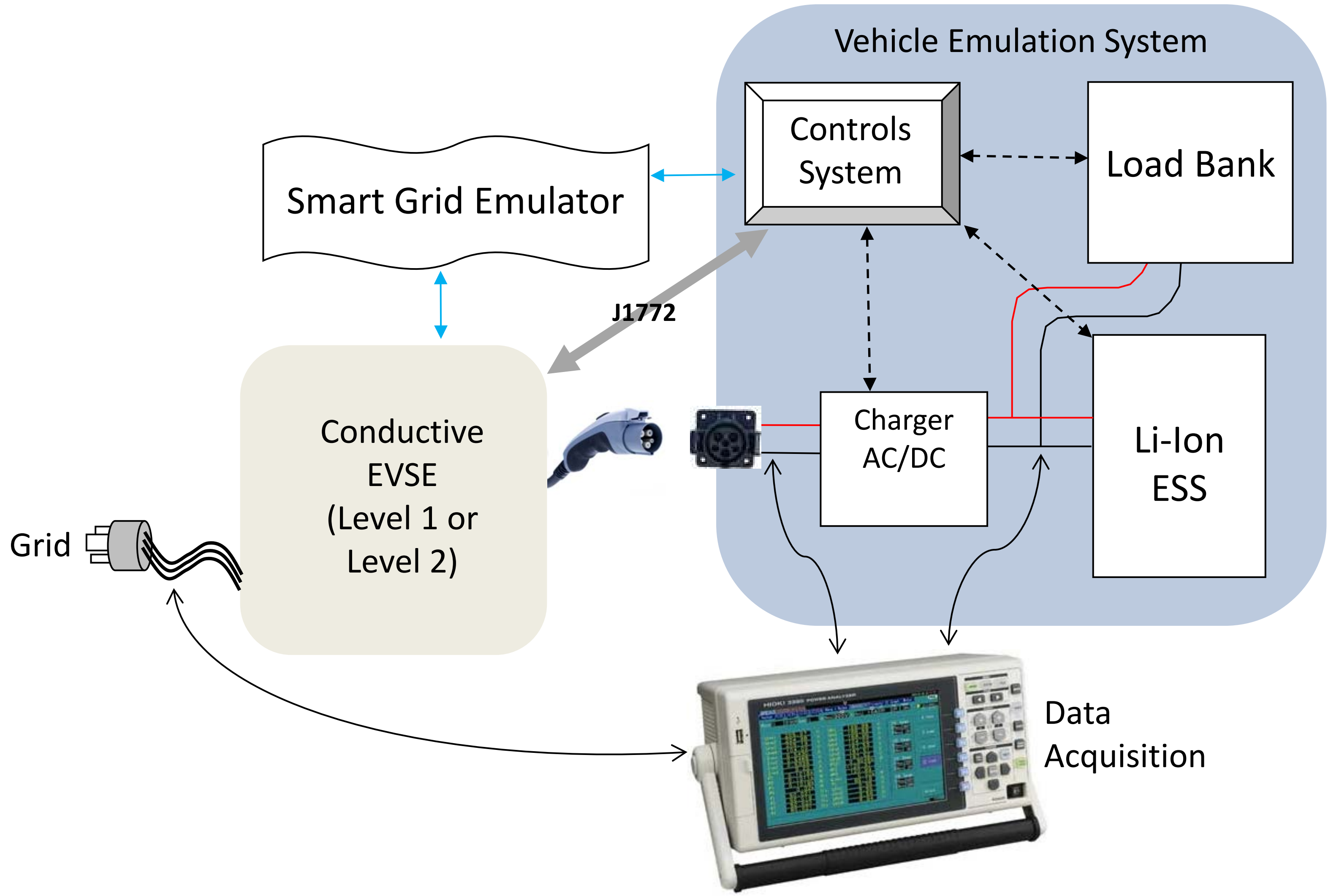
INL's Level 1 and 2 EVSE and DCFC Testing

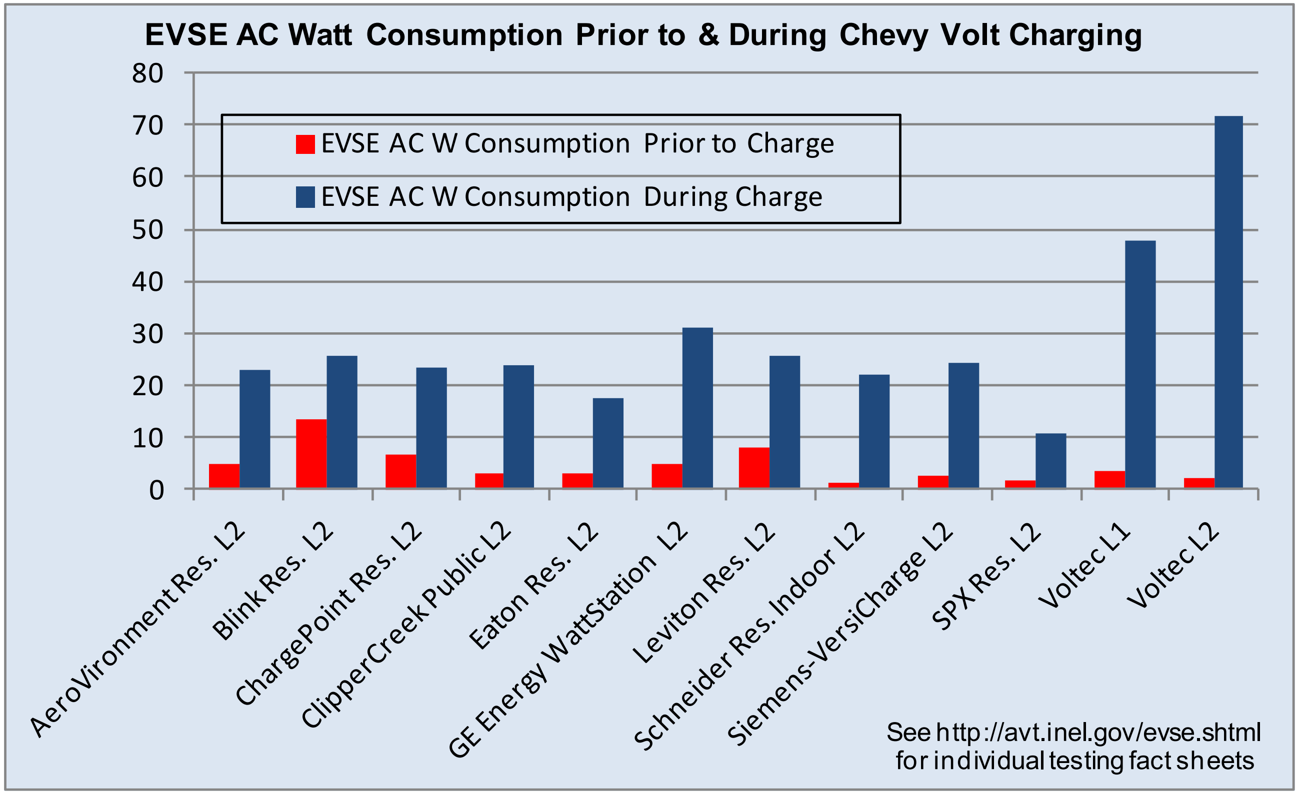
Conductive Efficiency? – It depends on where and when you measure it: 23% to 99.7%

EVSE Testing - Conductive



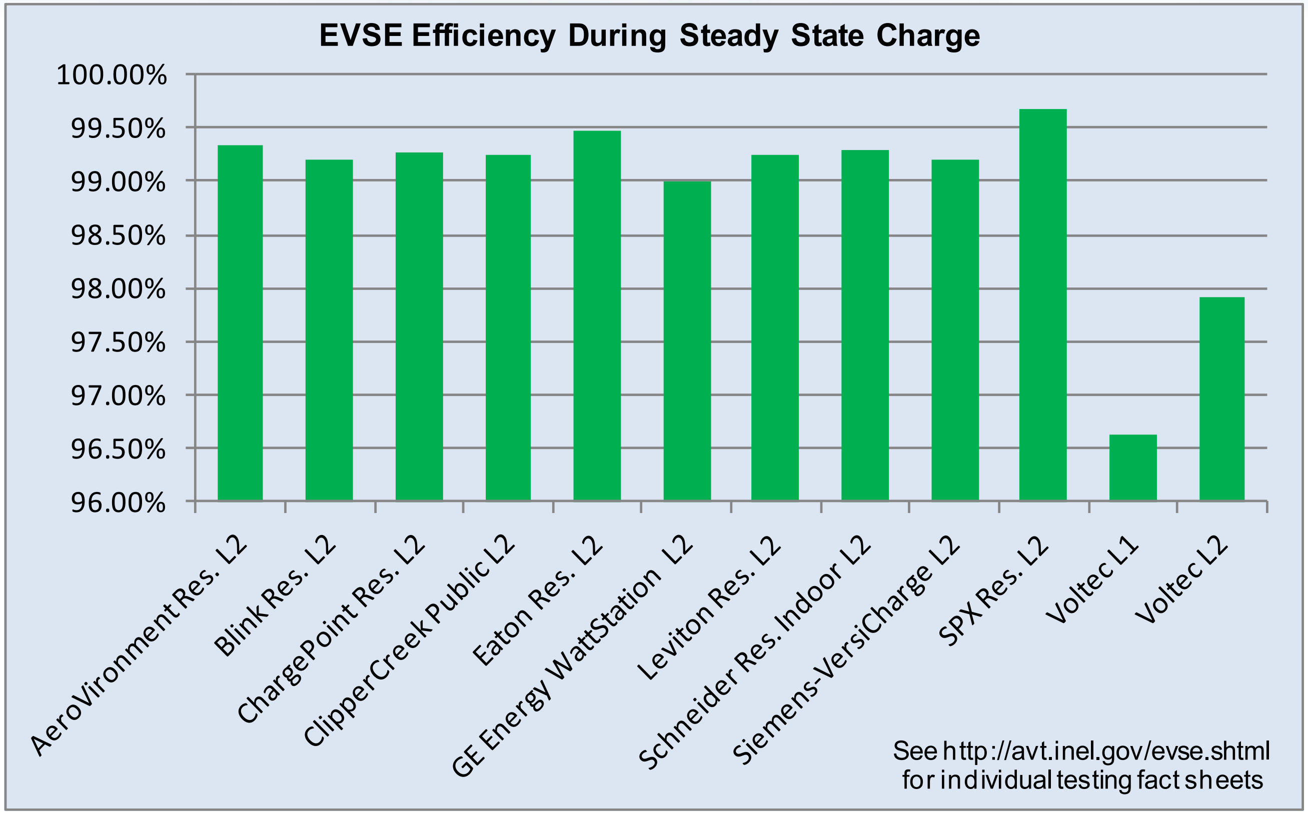
Conductive EVSE Energy Consumption

- **AC energy consumption at rest and during Volt charging benchmarked**



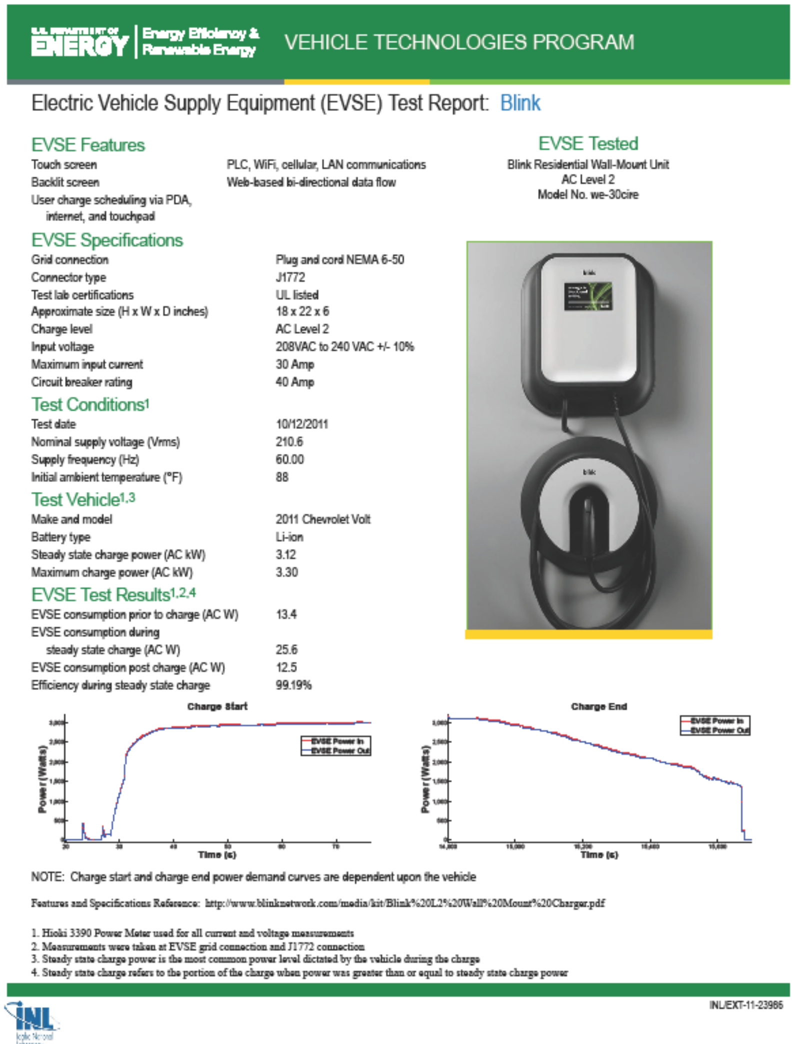
- **Most EVSE consume 13 W or less at rest. Higher power use at rest is tied to greater EVSE features and functionality**
- **During charging, most EVSE power use is under 30 W**

Conductive EVSE Charging Efficiency



- **Steady state charging efficiency benchmarked for EVSE only (at meter and J1772 connector). No onboard components included**
- **Most conductive EVSE 99+% efficient during steady state charge of a Volt**

Charging Efficiency Can Be Difficult to Quantify With A Single Number For All Conditions



VEHICLE TECHNOLOGIES PROGRAM

Electric Vehicle Supply Equipment (EVSE) Test Report: Blink

EVSE Features

Touch screen
Backlit screen
User charge scheduling via PDA, internet, and touchpad
PLC, WiFi, cellular, LAN communications
Web-based bi-directional data flow

EVSE Tested

Blink Residential Wall-Mount Unit
AC Level 2
Model No. we-30cire

EVSE Specifications

Grid connection	Plug and cord NEMA 6-50
Connector type	J1772
Test lab certifications	UL listed
Approximate size (H x W x D inches)	18 x 22 x 6
Charge level	AC Level 2
Input voltage	208VAC to 240 VAC +/- 10%
Maximum input current	30 Amp
Circuit breaker rating	40 Amp

Test Conditions[1]

Test date	10/12/2011
Nominal supply voltage (Vrms)	210.6
Supply frequency (Hz)	60.00
Initial ambient temperature (°F)	88

Test Vehicle[1,3]

Make and model	2011 Chevrolet Volt
Battery type	Li-ion
Steady state charge power (AC kW)	3.12
Maximum charge power (AC kW)	3.30

EVSE Test Results[1,2,4]

EVSE consumption prior to charge (AC W)	13.4
EVSE consumption during steady state charge (AC W)	25.6
EVSE consumption post charge (AC W)	12.5
Efficiency during steady state charge	99.19%

NOTE: Charge start and charge end power demand curves are dependent upon the vehicle

Features and Specifications Reference: http://www.blinknetwork.com/media/kit/Blink%20L2%20Wall%20Mount%20Charger.pdf

1. Hioki 3390 Power Meter used for all current and voltage measurements
2. Measurements were taken at EVSE grid connection and J1772 connection
3. Steady state charge power is the most common power level dictated by the vehicle during the charge
4. Steady state charge refers to the portion of the charge when power was greater than or equal to steady state charge power

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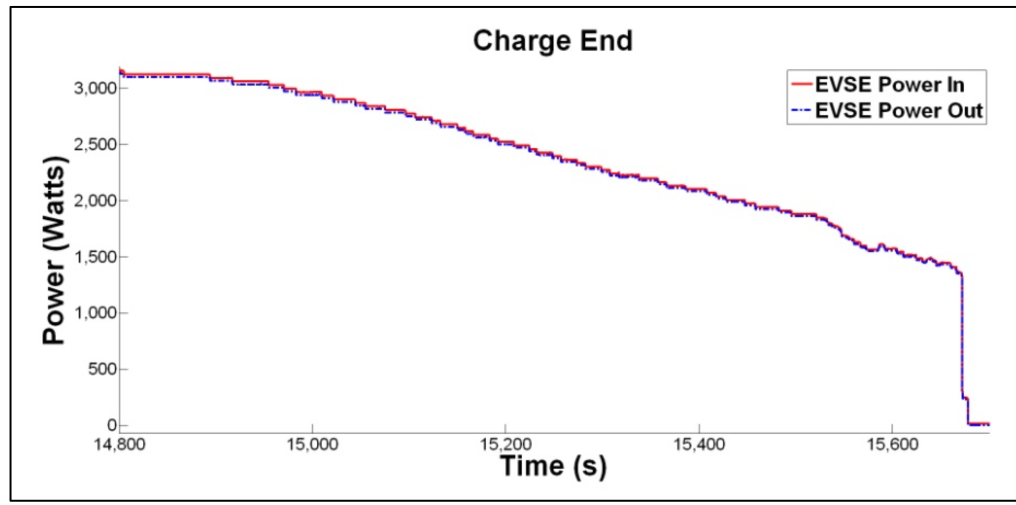
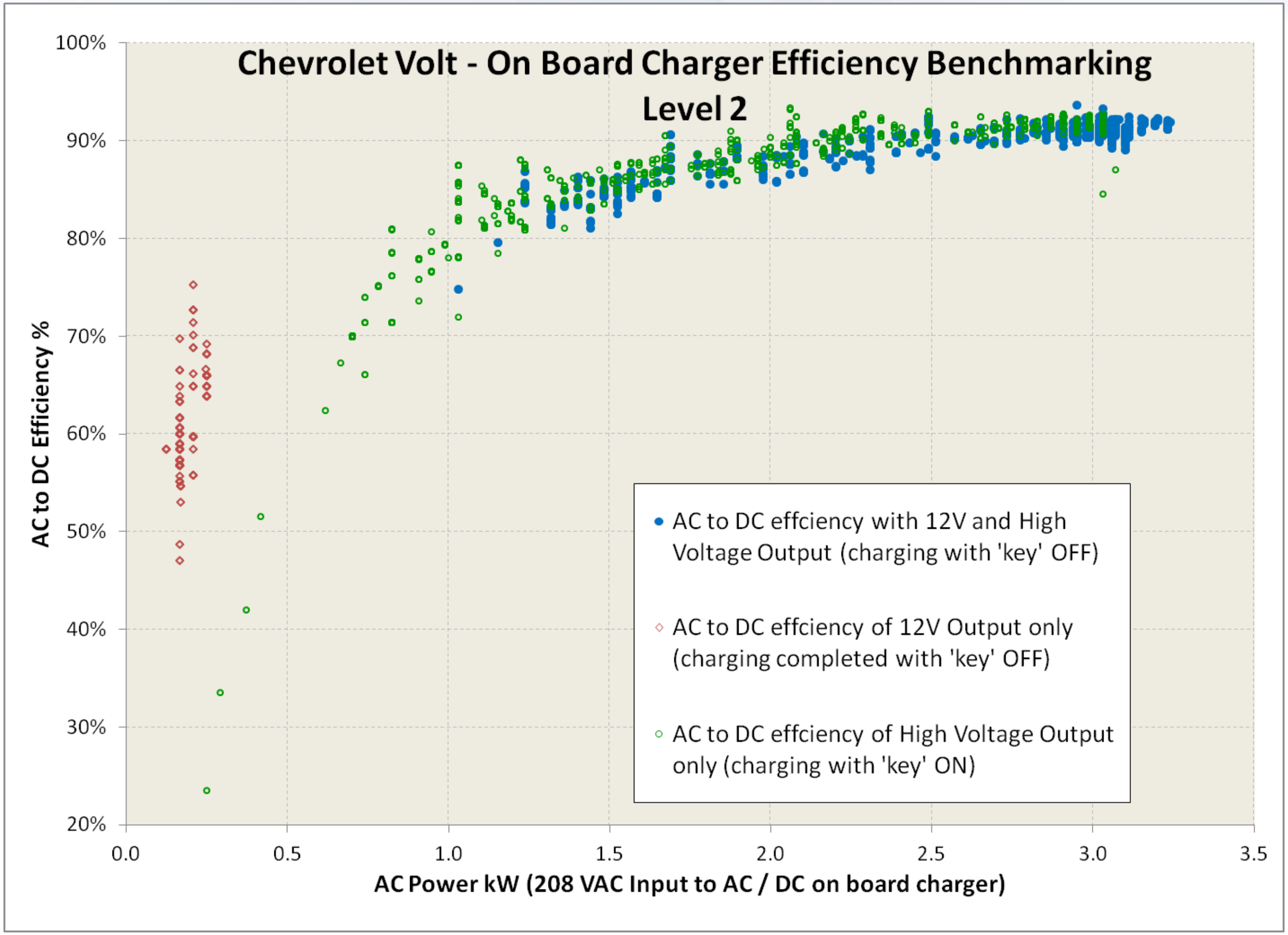


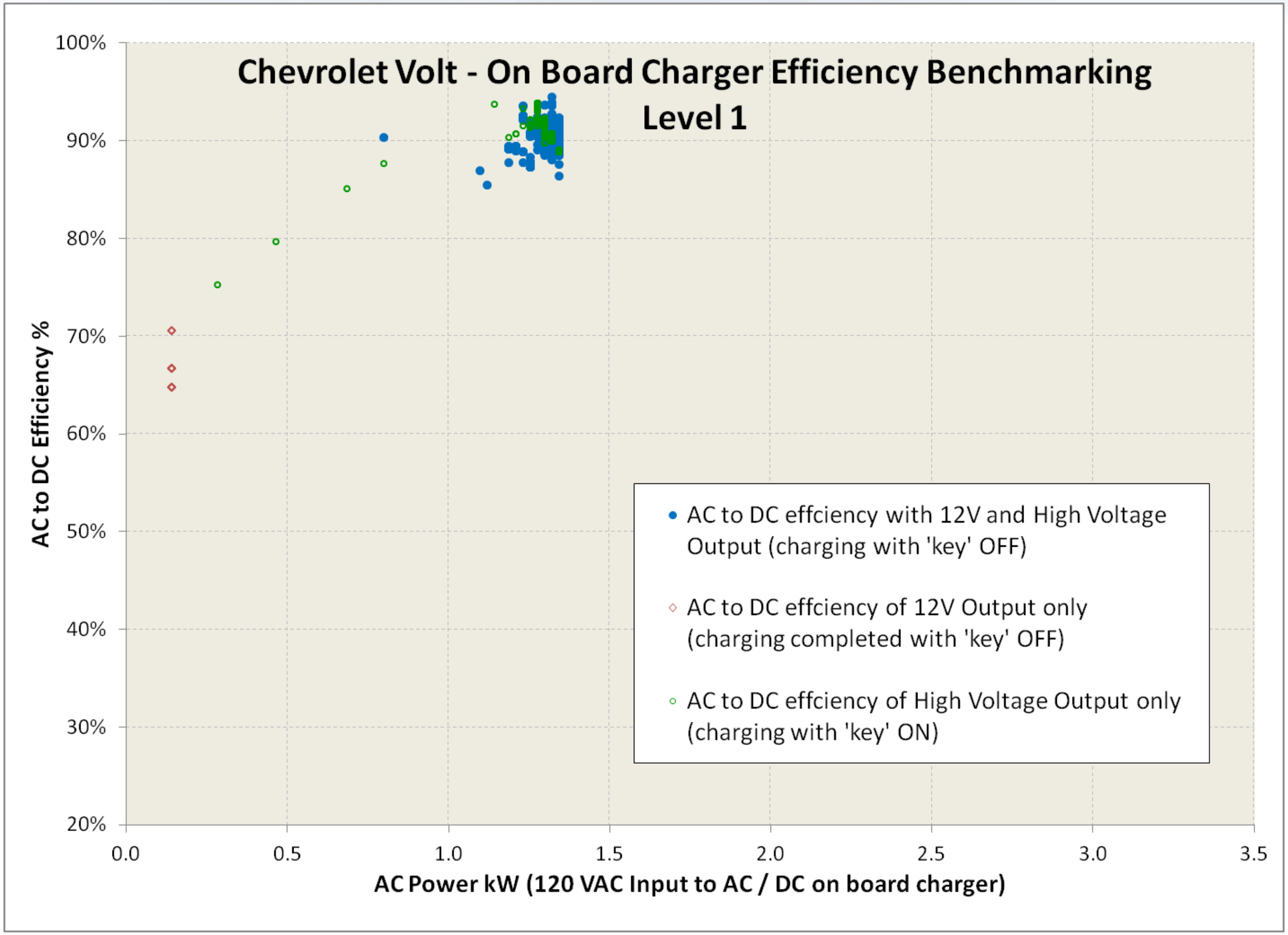
http://avt.inel.gov/pdf/evse/EVSEECOtalityBlink.pdf

Conductive System Benchmarking



Entire report can be found at:
http://avt.inel.gov/pdf/phev/EfficiencyResultsChevroletVoltOnBoardCharger.pdf

Conductive System Benchmarking



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DCFC Benchmarking – Leaf Charging


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

Production EVSE Fact Sheet: DC Fast Charger: Hasetec

Specifications

Grid connection	Hardwired
Connector type	CHAdeMo
Approximate size (H x W x D inches)	38 x 69 x 21
Charge level	DC Fast Charge
Input voltage	480 VAC - 3 Phase
Isolation Transformer[1]	75 kVA
Maximum input current[2]	120 Amp

Test Conditions

Test date	10/23/2012
Supply frequency (Hz)	60
Initial ambient temperature (°F)	65

Vehicle Charged

Make and model	2011 Nissan Leaf
Battery type	Li-ion
Initial Leaf ESS State of Charge[3]	9%
Final Leaf ESS State of Charge[3]	86%

DCFC Test Results[3, 4]

Peak Power draw from Grid (AC kW)	53.1
Energy from grid (AC kWh)	15.0
Peak Charge Power to Leaf ESS (DC kW)	47.1
Energy delivered to Leaf ESS (DC kWh)	13.3
Charge time (min:sec)	31:40
Overall Charge Efficiency (480VAC to ESS DC)	88.7%

DC Fast Charger Tested

Hasetec L06-3P3W 50KW

1. HPS Sentinel dry type Isolation Transformer
2. Manufacture specification = 125A max, this installation is configured to 120A max due to supply restrictions
3. Vehicle CAN message data acquisition and Hasetec DC output watthour meter used for DC measurements
4. Squre D WattHour meter used for 480VAC energy measurement on feed to transformer

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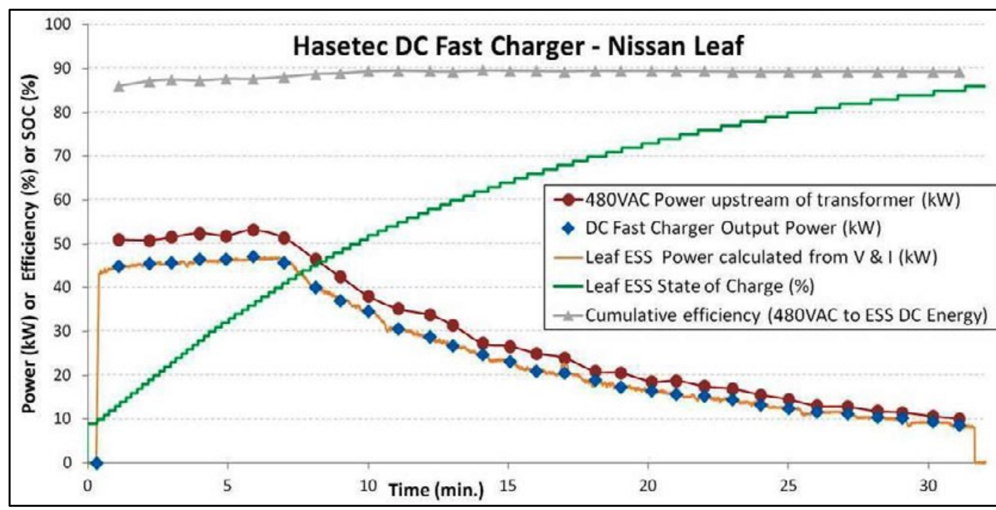
- 88.7% Overall charge efficiency (480VAC to ESS DC)
- 53.1 AC kW peak grid power
- 47.1 DC kW peak power to Leaf energy storage system (ESS)
- 15.0 Grid AC kWh and 13.3 DC kWh delivered to Leaf ESS



http://avt.inel.gov/pdf/evse/DCFCHasetec.pdf

INL Testing Support to DOE Office of Electricity and Energy Reliability for DE-FOA-000554 Smart Grid Capable EVSE

DE-FOA-000554 Smart Grid Capable Electric Vehicle Supply Equipment - Objective

- ***"……A goal of the OE Smart Grid Research and Development (R&D) Program is to develop and implement smart grid technologies to support transportation electrification. A near-term objective of the program is to reduce electric charging infrastructure costs in support of the President's initiative of putting one million electric vehicles on the road by 2015…."***

DOE Office of Electricity Delivery and Energy Reliability – FOA 554 Smart EVSE Support

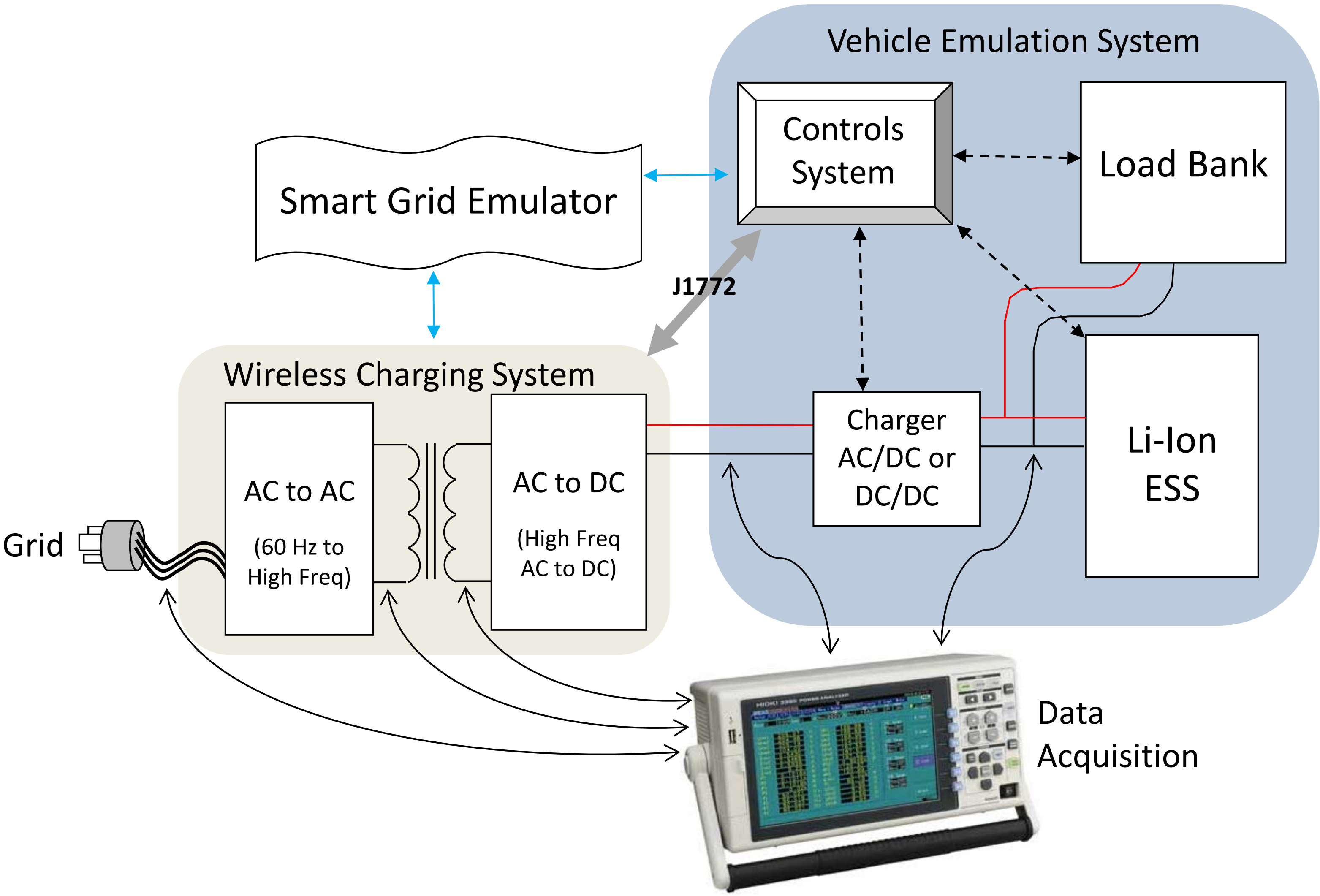
- **DOE's OE selected four awardees**
  - **Delta Products Corporation**
  - **Eaton Corporation**
  - **General Electric Corporation**
  - **Siemens Corporation (Corporate Research & Technology)**
- **Two of four NDAs signed and getting close on the others**
- **Two kickoff meetings conducted at INL**
- **Fall of 2013 deliverables to INL and Argonne**
- **INL will conduct "normal" Level 2 conductive EVSE testing as well as minimal communications testing**
- **INL will conduct cyber security testing of the EVSE and back office control/communications systems**

Levels 1 & 2 EVSE & DC Fast Charging Summary

- Consumers Energy, ECOtality, INL and SMUD (Sacramento Municipal Utility District) test locations provided access to EVSE and DCFC equipment and vehicles
  - No need to purchase charging infrastructure, vehicles, and a site to host equipment used one time
  - Allows INL to test charging infrastructure at much lower cost to DOE
  - Allows for testing results in real-world setting
  - Strengthens working relationships and allows for refinement of test plan for FOA deliverables
- The first thirteen EVSE and DCFC units tested and published
- INL is conducting cyber security testing of an existing Level 2 EVSE. Great prep for FOA cyber security testing
- INL is considering testing other Level 1 and 2 EVSE, and DCFC units

DOE-FOA-000667 Wireless Charging for Electric Vehicles

Laboratory EVSE Testing - Wireless



DE-FOA-000667 Wireless Charging for Electric Vehicles - Objective

- "……***research and develop a production-feasible wireless charging system, integrate the system into a production-intent vehicle, and to demonstrate the technology's readiness to deliver the benefits of static (and possibly quasi-dynamic) wireless charging to drivers of light-duty…..Grid-Connected Electric Drive Vehicles (GCEDV)"***

FOA 667 Awardees

- **Oak Ridge National Laboratory**
  - **Evatran**
  - **Clemson University ICAR**
  - **General Motors**
  - **Toyota**

- **Hyundai America Technical Center Inc.**
  - **Mojo Mobility**

- **In three Phases, INL will test deliverables from the two lead FOA 667 awardees**

FOA 667 Phase I

- **Awardees develop production-feasible wireless charging system**
- **INL Tests Performed at End of Phase (1 year)**
  - **Efficiency Test > 85% ?**
  - **Power Test > 3.3 kW ?**
  - **Gap Spacing and Alignment Flexibility ?**
  - **Electric Field Emissions**
  - **Magnetic Field Emissions**
  - **Object Detection**
  - **Power Factor**
- **GO / NO-GO to Phase II?**

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FOA 667 Phase II

- **Awardees Integrate system into production-intent vehicle**
- **INL Tests Performed at End of Phase (another 1 year)**
  - **Same tests as Phase I**
  - **And, Vehicle Range (UDDS)**
    - **PHEV & EREV: > 10 miles**
    - **EV: > 80 miles**
- **Compare performance with J1772 Conductive Charge System**
- **GO/ NO-GO to Phase III?**

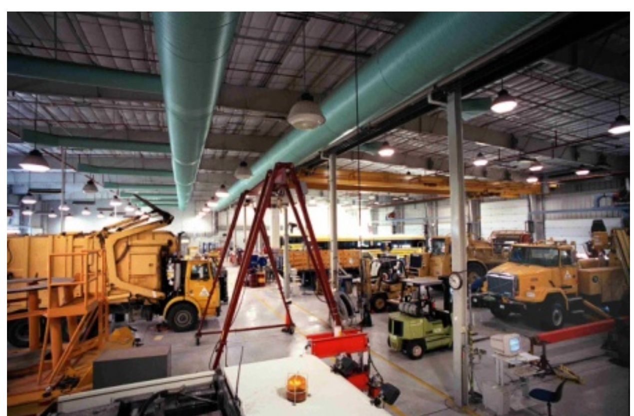
FOA 667 Phase III

- **Awardees demonstrate 5 vehicles with 5 charging stations**
- **Awardees provide one vehicle and charging station to DOE within 3 months**
- **INL performs evaluations for 3 months**
- **Same as Phase II, plus fleet operations:**
  - **Operational Safety**
  - **Convenience**
  - **Reliability**
  - **Flexibility**
  - **Efficiency**
  - **Use Pattern**
  - **Range Capability**
  - **Interoperability**
- **Awardees provide a regular transfer of raw data to INL from the other four vehicles**

INL Wireless Testing Equipment and Facilities

INL Wireless Interoperability Test Bed

- **Existing vehicle and laboratory testing capabilities**
  - **Multiple anechoic test chambers existing**
  - **100 miles of high speed primary and secondary roads**
  - **800 square miles of no measureable background noise**
  - **80,000 square foot vehicle support facility**
  - **<-30 ^{o}C (winter) and >40 ^{o}C (summer) variability**
  - **625 existing battery test channels (ingrained understanding of data collection process)**
  - **See next slides for specific wireless lab capabilities**



INL Wireless Charging Bench Testing

Grid Power
480 & 240 VAC

Hioki Power
Meter 3390

Chroma
AC Load

Chroma
DC Load

Fiberglass
Unistrut
Secondary Coil
Support

Narda EM Field
Meter (EHP-200)

Polycarbonate
Primary Coil
Support

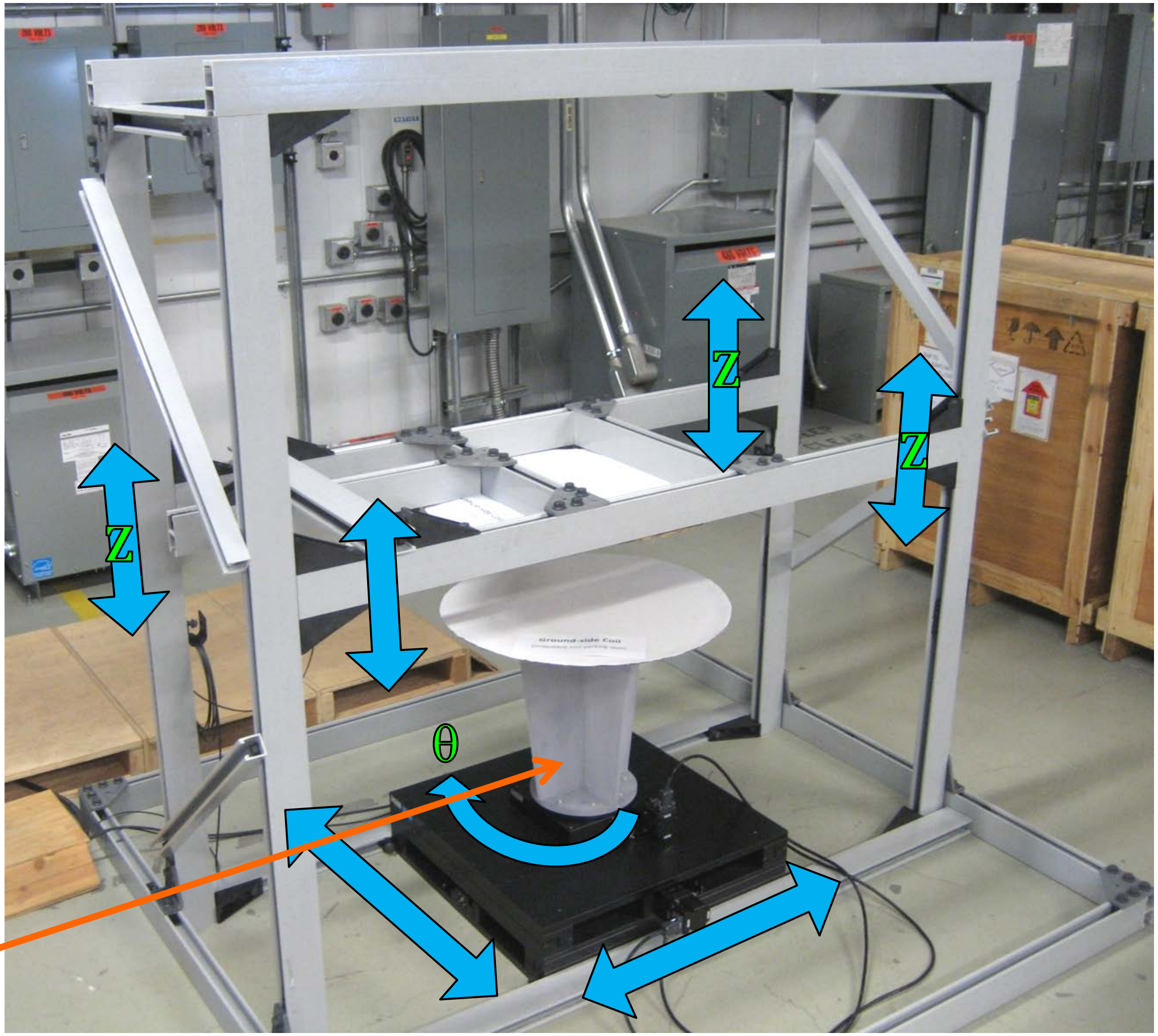
Multi-Axis
Positioning
System

Custom LabVIEW Host and
Data Acquisition

INL Wireless Charger Coil Positioning

- **Primary Coil position controlled**
- **Secondary Coil held in fixed position**
- **Multi-axis control via LabVIEW software (X, Y, q)**
- **Manual positioning in Z direction and Tilt from unequal Z positioning**
- **NARDA EHP-200a mounted on rail**

Polycarbonate Primary Coil Support



Wireless Charging Summary

- Laboratory bench testing capability and safety issues refined with SAE, UL and automotive OEM inputs
- Supports SAE J2954 committee and UL work and refinement of their respective testing procedures
- First NDA signed and working on five more
- First two non-FOA wireless charging systems scheduled for mid April delivery to INL
- In discusses with another provider for a May delivery. This testing supports test plan refinement for FOA testing
- Providing data to ORNL's dynamic wireless charging feasibility study
- Supporting EERE DOE-OE FOA development and enhancement of smart grid wireless charging systems
- Exploring other testing options that involve avoiding high purchase costs

Other Charging Infrastructure Related Testing Activities

Additional Charging Infrastructure Testing

- **Initiated field and lab DC Fast Charge and Level 2 charging study of impacts on battery life in 6 Nissan Leafs**
  - **Two vehicles driven on road and L2 charged**
  - **Two vehicles driven the identical routes and DCFC charged**
  - **One L2 and 1 DCFC tested in battery lab**
  - **At 10k miles each vehicle demonstrated similar minimal capacity fade**
  - **(see Matt Shirk's Presentation for additional information)**

- **INL has initiated data collection from ~500 Level 2 EVSE as they are deployed throughout New York State.**
  - **Conducted in partnership with NYSERDA, NYPA, Port Authority of NY / NJ, and Energetics**

Additional Charging Infrastructure Testing

- **INL will manage Advanced Vehicle Testing Activities conduct of a 30 EVSE and DCFC compatibility testing with 10 OEM vehicles**
  - **Partners include OEMs, SAE, UL, EVSE and DCFC manufacturers, and ECOtality**
- **Initiated data collection project for six Nissan Leafs in New York City taxi fleet. INL will receive data from six Level 2 EVSE, three DC Fast Chargers, and six Leafs**
  - **Project partners and data providers include the NYC Taxi & Limousine Commission, Nissan, Aerovironment, and ECOtality**

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Acknowledgement

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

More Information

http://avt.inl.gov

INL/MIS-13-28724