Integration Technology for PHEV-Grid-Connectivity, with Support for SAE Electrical Standards

2010 DOE Hydrogen Program and Vehicle Technologies Annual Merit Review

June 09, 2010

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Argonne National Laboratory

Sponsored by Lee Slezak

Project ID #VSS025

U.S. Department of Energy
Energy Efficiency and Renewable Energy
Bringing you a prosperous future where energy is clean, abundant, reliable, and affordable

Project Overview

Timeline

- Support of SAE PHEV-Grid related standards started in 2007
- FreedomCAR Grid Interaction Tech Team (GITT) initiated 3Q09
- Grid connectivity project proposals approved 1Q10
- SAE J2907™ Motor Standards Committee Co-chair
- 40% complete on grid connectivity demonstration activities

Barriers

- Many vehicles charging from the grid interact and compete with existing electrical loads.
- Alternative approaches exist to intelligently manage vehicle charge and communication.
- Interoperability of vehicle-grid communication and hardware connections is a necessity for effective infrastructure deployment.
- Low cost, secure and validated technology and communication standards are required coincident with PHEV/EV market introductions.

Budget

- FY2010- $300k received for SAE Stds
- FY2010- $460k received +$470k pending for new projects

Partners

- Utilities (DTE Energy, Southern Cal. Edison, Communications technology vendors)
- EVSE suppliers (Clipper Creek, Coulomb, Ingeteam, Consat, ETEC)
- Vehicle OEMS (Ford, GM, Chrysler)

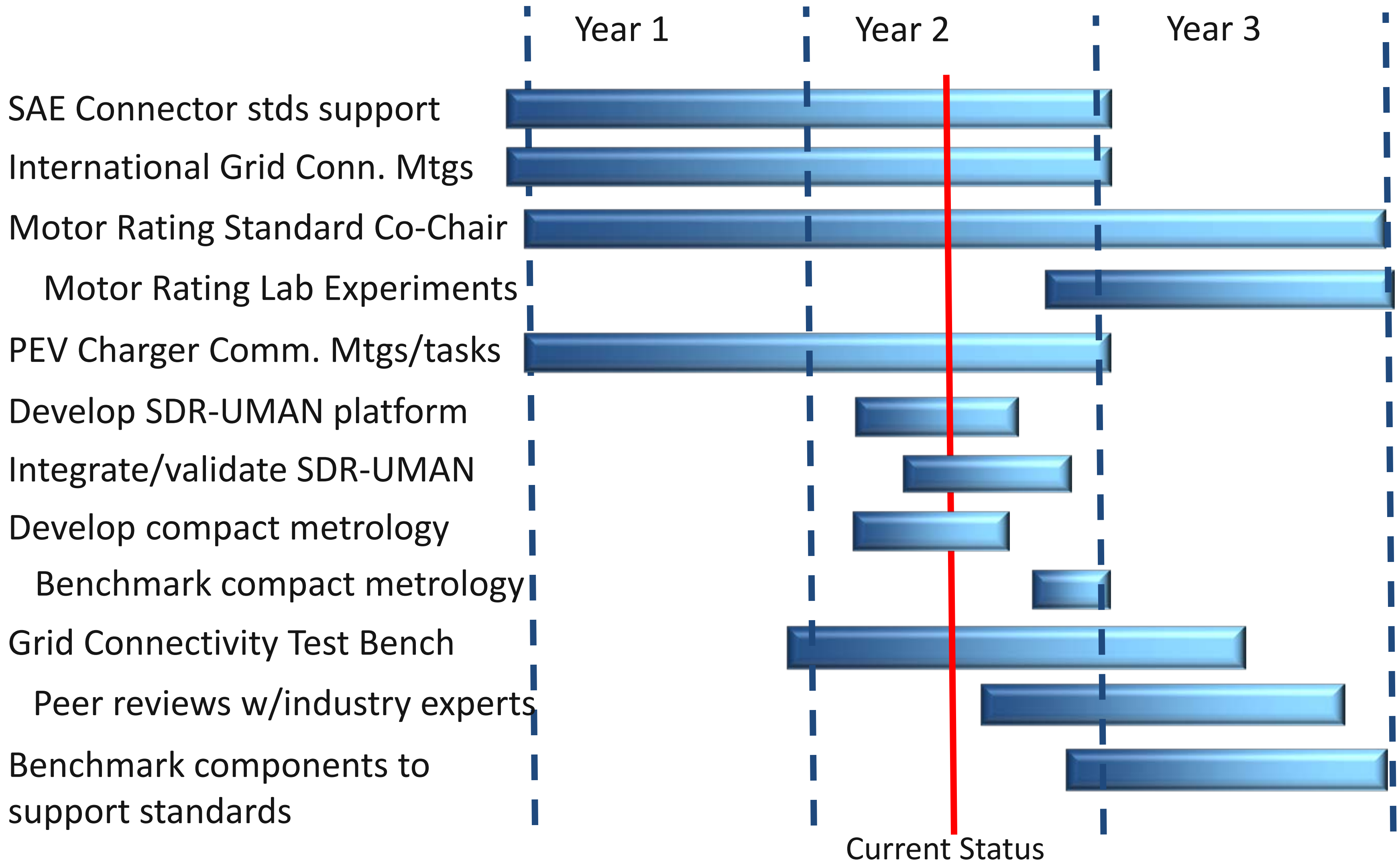
Objectives

- Address codes and standards requirements to enable wide-spread adoption of electric-drive transportation.

- Demonstrate improved grid connectivity of electric vehicle charging infrastructure via lower cost, secure, universalized wired and wireless communications technologies.
  - Produce functional demonstration of 'Software Defined Radio' (SDR) technology in a low cost field programmable gate array (FPGA) device implementing Universal Metropolitan Area Network (UMAN).
  - Demonstrate compact AC power measurement sub-metering system with wireless communication to Advance Meter Infrastructure (AMI) as alternative to secondary dedicated EV charging meter installation

- Validate in a systems context performance targets
  - Power Electronics and Energy Storage Technology electric motor ratings standards activity
  - Energy storage system communications technology validation.

Milestones


Year 1
Year 2
Year 3
SAE Connector stds support
International Grid Conn. Mtgs
Motor Rating Standard Co-Chair
Motor Rating Lab Experiments
PEV Charger Comm. Mtgs/tasks
Develop SDR-UMAN platform
Integrate/validate SDR-UMAN
Develop compact metrology
Benchmark compact metrology
Grid Connectivity Test Bench
Peer reviews w/industry experts
Benchmark components to support standards
Current Status

Approach - SAE Codes and Standards

- Address codes and standards requirements to enable wide-spread adoption of electric-drive transportation with Smart Grid Interoperability.
  - Engage with suppliers, academia, automotive industry, and government officials to continuously assess state-of-the art
  - Provide technically sound guidance to Standards committees
  - Evaluate and validate hardware and communication protocol proposals
  - Encourage consistency with international harmonization (Graphic: Japan and US)

JARI 200A compared to 1772™ Combo Amphenol

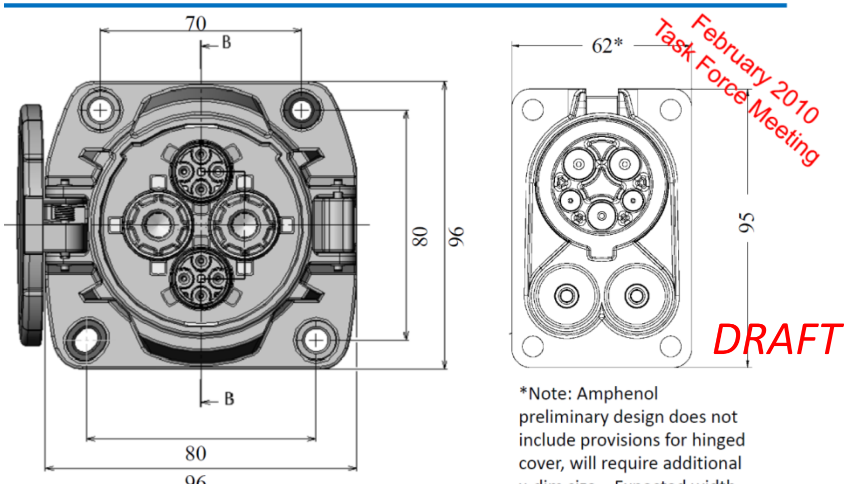


Image from Yazaki 200A DC presentation to SAE J1772™ workgroup, Oct 2009.

*Note: Amphenol preliminary design does not include provisions for hinged cover, will require additional x-dim size. Expected width similar to Yazaki inlet (left).

Approach - SAE Codes and Standards

- SAE 2907™ Electric motor ratings standards lack consensus based definitions of usage cycles, impulse, peak/transient, steady state.
  - Benchmark representative sample motors use to create draft usage cycle definitions.
  - Benchmark impact on rating as a function of motor cooling methods used in cycle definitions.
  - Utilize vehicle test results to determine in-vehicle peak demand.

Example motor ratings- motor on left is 50kW, on right is 60kW but smaller

Proximity loss measurement and extrapolation for high speed/higher frequency motors as a function of winding materials and methods

- SAE 2894™ Vehicle Battery Charger Power Quality and Efficiency test methods.
  - Use benchmark in-vehicle charger performance data, validation and iteration of sub-parts for component level testing on a load bank

Approach - Grid Connectivity Technology Development & Validation of Vehicle Charging Messages

- A vehicle-grid communications test bench will be created to support SAE J2847/1™ (Vehicle charger-utility communication messages)
- Test Bench emulates Utility system messages and has physical battery charger, human/machine interface, and electric vehicle supply equipment.
- Compact Metrology system as sub-metering for charging vehicles is included

Technical Accomplishments

- Initiated and managed subcontracted projects for Grid Connectivity Technology Development and Validation of Vehicle Charging Messages

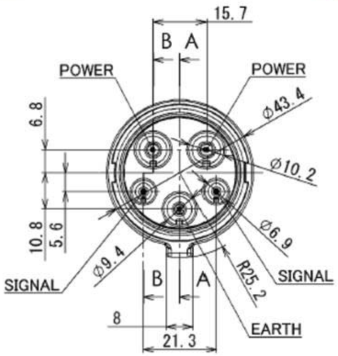
- Demonstrated Phase 1 limited capability grid connectivity of electric vehicle charging infrastructure using lower cost, secure, universalized wired and wireless communications technologies. (PLC modem, UMAN, zigbee)

- Produced functional demonstration of ‘Software Defined Radio’ (SDR) technology in a low cost field programmable gate array (FPGA) device implementing Universal Metropolitan Area Network (UMAN) vehicle-grid enabling interoperability of widely varying infrastructure resources.

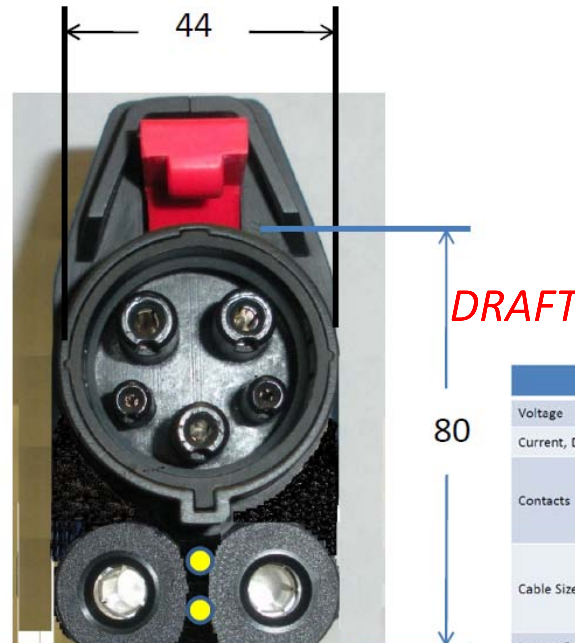
- Defined specifications for non-contact, non-ferrite based, current sensor (flux gate magnetometer) and signal processing electronics.

Technical Accomplishment - Example

- SAE J1772™ AC Coupler approved January 2010



- SAE J1772™ DC Coupler design in process with synergy to AC coupler (allowing AC and DC coupler interface compatibility)



Preliminary Specifications		
Voltage	600 VDC	
Current, DC	200 A	
Contacts	DC Power	8.0 mm diameter
	Ground	2.8 mm diameter
	Signal	1.5 mm diameter
Cable Sizes	DC Power (2)	AWG 1/0 (50 mm²)
	Ground (1)	AWG 6 (15 mm²)
	Signal (4)	AWG 18 (0.75 mm²)
Ingress Protection		IPX5
Weight Estimate, including 7.5m cable & mechanical assist		10.75 Kg (23.7 Lbs.)
Insertion / Extraction Force With Mechanical Assist		< 60 N

Collaborations

- Grid Connectivity Projects
  - National Laboratories; PNNL, NREL, INL
  - Technology experts such as University of Michigan-Dearborn on SDR-UMAN, Alektrona for Zigbee Home Gateway, Universal Gridworks for Compact Metrology and sensor development
  - Utilities; DTE Energy (Detroit), Southern California Edison
  - EVSE Manufacturers; Clipper Creek, Coulomb, Ingeteam

Support of SAE Standards

- SAE J2907 ™Motor Ratings;
  - ORNL
  - Vehicle OEMS; GM, Ford, Chrysler, Toyota, Nissan, John Deere, Tesla, Fisker
  - Motor manufacturers; Remy, G.E., Bosch, Azure Dynamics, Magna, etc.
- SAE J2894™ Charger Efficiency/Quality
  - Charger manufacturers; Delta-Q, Magna, Azure Dynamics)
  - Utilities; PGE, SCE

Activities for Next Fiscal Year

- Continue to investigate limitations and propose solutions for vehicle-grid communications technologies, with emphasis on interoperability between countries as well as regions (utility districts).
  - Implement other internationally compatible communications protocols in Software Defined Radio (SDR) technology.
- Validate in a systems context performance targets
  - Power Electronics and Energy Storage Technology electric motor ratings standards
    - Expand benchmark hardware experiments to support validation of methods used to determine electric motor rating standards, with emphasis on cooling methods and impact.
  - Energy storage system communications technology

Summary

- Guided grid connectivity technology between electric vehicles while charging and the utility infrastructure for lower cost, secure, universalized wired and wireless communications technologies.

- Provided support and leadership for codes and standards required to enable wide-spread adoption of electric-drive transportation.

- Defined and managed GITT projects to create Vehicle Grid communication testbed.

- Validated electric drivetrain components in systems context for performance targets.

Additional Slides

SAE PEV/EVSE Related Standards

http://www.sae.org/servlets/product?PROD_TYP=STD&HIER_CD=TEVHYB&WIP_SW=YES&ORDERBY=DOCNUM

- **J1772™** SAE Electric Vehicle and Plug in Hybrid Electric Vehicle Conductive Charge Coupler *(J1772-DC under development)*

- **J2836™** Use Cases for Communication between Plug-in Vehicles and ..
  - **J2836/1** The Utility Grid
  - **J2836/2** The Supply Equipment (EVSE)
  - **J2836/3** The Utility Grid for Reverse Power Flow
  - **J2836/4** For Diagnostic Communication for Plug-in Vehicles
  - **J2836/5** Their customers.

- **J2847™** Communication between Plug-in Vehicles and …
  - **J2847/1** The Utility Grid
  - **J2847/2** The Supply Equipment (EVSE)
  - **J2847/3** The Utility Grid for Reverse Power Flow
  - **J2847/4** For Diagnostic Communication for Plug-in Vehicles
  - **J2847/5** Their customers.

- **J2931** ™ *Electric Vehicle Supply Equip. (EVSE) Comm. Model*

Current SAE Codes/Stds Activities

- **SAE J2907™ (T. Bohn- chair)** *Power rating method for automotive electric propulsion motor and power electronics sub-system*
  Scope: Test method and conditions for rating performance of electric propulsion motors as used in hybrid electric and battery electric vehicles.
  Rationale: Promote uniform testing method and harmonize global markets. At present there are no unambiguous standards for rating propulsion motors.

- **SAE J2908™** *Power rating method for hybrid-electric and battery electric vehicle propulsion.*

  Scope: Test method and conditions for rating performance of complete hybrid-electric and battery electric vehicle propulsion systems reflecting thermal and battery capabilities and limitations.
  Rationale: Promote uniform testing method and harmonize global markets. At present there are no unambiguous standards for rating hybrid-electric and battery electric propulsion systems.

ANL Standards Related Work

- **SAE J2894/1™** *Power Quality Requirements for Plug In Vehicle Chargers - **Part 1: Requirements***

  Scope: The intent of this new document is develop a recommended practice based on EPRI TR-109023 EV Charging Equipment Operational Recommendations for Power Quality that will enable vehicle manufacturers, charging equipment manufacturers, electric utilities and others to make reasonable design decisions regarding power quality. The three main purposes are as follows: 1.To identify those characteristics of the AC service that may significantly impact the performance of the charging equipment. 2.To identify those parameters of PEV battery charging that must be controlled in order to preserve the quality of the AC service. 3.To recommend target values for power quality, susceptibility and power control parameters which are based on current U.S. and international standards. Furthermore, these recommended values should be technically feasible and cost effective to implement into PEV battery charging equipment.

  Rationale: The proliferation of nonlinear loads such as switching power supplies, variable frequency drives and battery chargers have led to a higher level of concern over the impacts of power quality. More precisely there are three major reasons for these concerns: 1.Sensitive microprocessor based devices are more susceptible to power variances. 2.The increased number of non-linear devices has resulted in the rise of harmonics onto the power system leading to reduced system reliability. 3.The vast networkability of devices has led to larger consequences from failure. Ultimately, the success of widespread plug-in electric vehicle (PEV) charging depends in major part to the reliability of both the electric grid and the charging equipment. To meet the needs of PEV operators, PEV charging equipment must be sufficiently robust, reliable and cost effective. In order to achieve this goal, equipment manufacturers along with electric utility companies must understand the characteristics of the AC service to which the equipment will be connected, as well as the impact chargers can have on service quality. The charger is the conduit through which energy moves from the AC line to the vehicle's battery and it controls the rate and manner of energy transference to the battery. For practical purposes, it is the charger that controls power quality.

ANL Standards Related Work

- **SAE J2894/2 ™***Power Quality Requirements for Plug In Vehicle Chargers - **Part 2: Test Methods***

  Scope: This Recommended Practice is based on EPRI's TR-109023 - SEV Charging Equipment Operational Recommendations for Power Quality. The document will enable vehicle manufacturers, charging equipment manufacturers, electric utilities and others to make reasonable design decisions regarding power quality that are technically feasible and cost effective to implement. —Will address bi-directional energy flow. This Recommended Practice will include guidelines for: —Total Power Factor —Power Conversion Efficiency —Total Harmonic Current Distortion —Current Distortion at Each Harmonic Frequency —Plug in Electric Vehicle Charger Restart After Loss of AC Power Supply —Charger / Electric Vehicle Supply Equipment AC Input Voltage Range —Charger / Electric Vehicle Supply Equipment AC Input Voltage Swell —Charger / Electric Vehicle Supply Equipment AC Input Voltage Surge (Impulse) —Charger / Electric Vehicle Supply Equipment AC Input Voltage Sag —Charger / Electric Vehicle Supply Equipment AC Input Frequency Variations —In-Rush Current —Momentary Outage Ride-Through
  Rationale: Introduce updated technology

- **SAE J1772™** *SAE Electric Vehicle and Plug in Hybrid Electric Vehicle Conductive Charge Coupler*

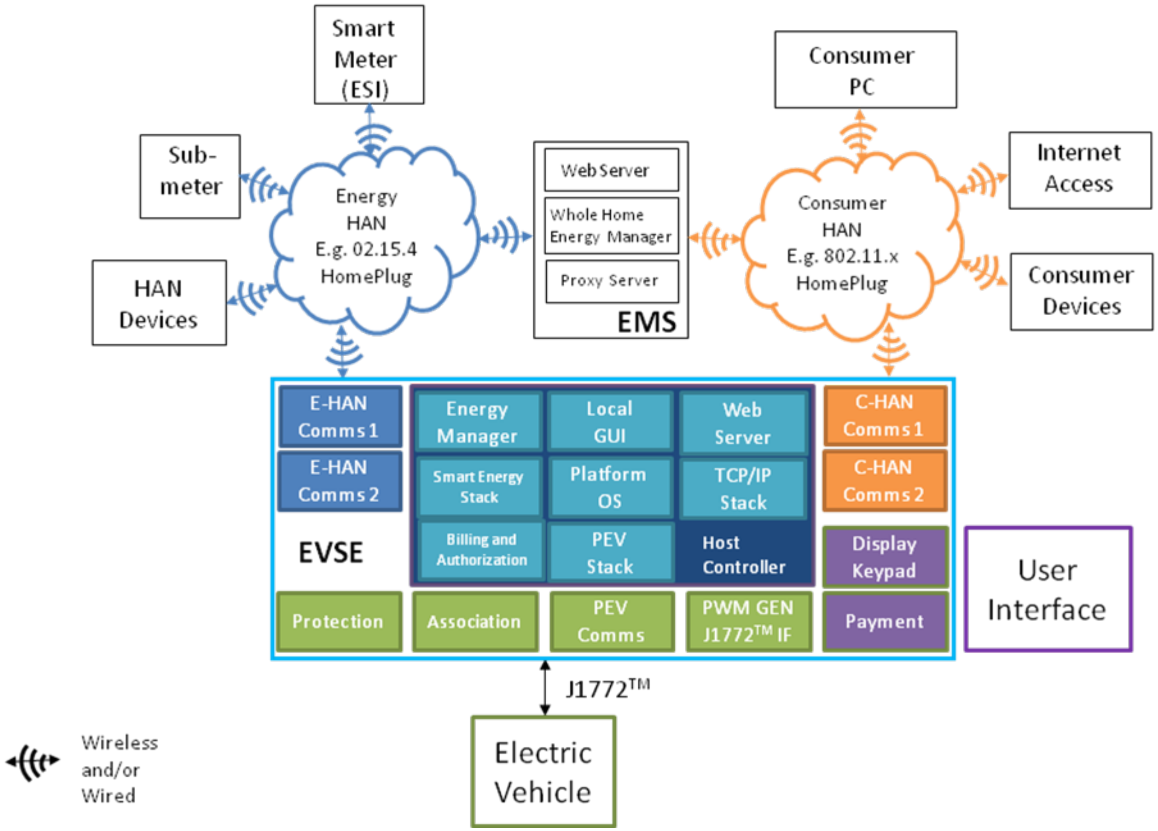
  Scope: This SAE Recommended Practice covers the general physical, electrical, functional and performance requirements to facilitate conductive charging of EV/PHEV vehicles in North America. This document defines a common EV/PHEV and supply equipment vehicle conductive charging method including operational requirements and the functional and dimensional requirements for the vehicle inlet and mating connector.

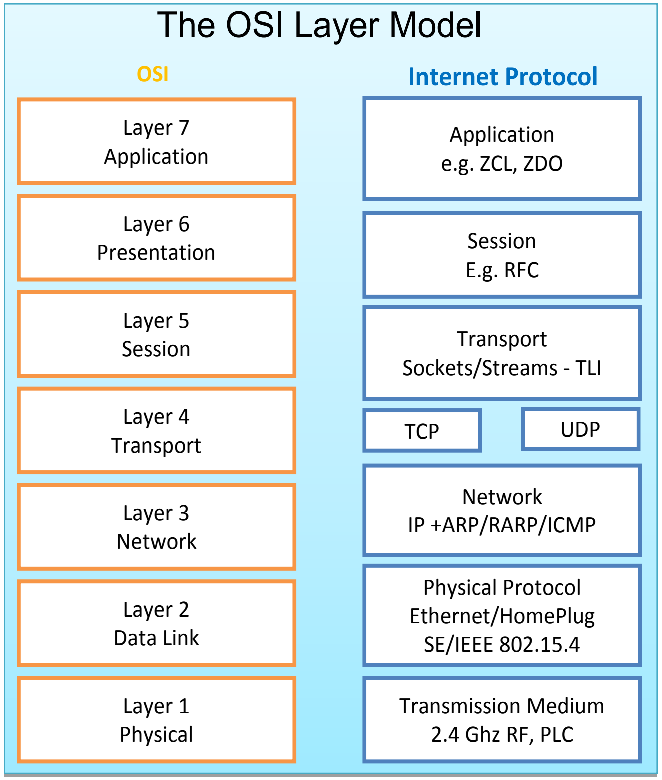
ANL Standards Related Work

- **SAE J2931™** *Electric Vehicle Supply Equipment (EVSE) Communication Model*
  Scope: This SAE Recommended Practice establishes the digital communication requirements for the Electric Vehicle Supply Equipment (EVSE) as it interfaces with a Home Area Network (HAN), Energy Management System (EMS) or the Utility grid systems. This Recommended Practice provides a knowledge base addressing the communication medium functional performance and characteristics, and interoperability to other EVSEs, Plug-In Vehicles (PEVs) and is intended to complement J1772" but address the digital communication requirements associated with smart grid interoperability.
  Rationale: This SAE Recommended Practice is intended to provide a common set of requirements as various EVSE suppliers build their product and interface with several Plug-In Vehicle manufacturers and the HAN/EMS/Utility to assure smart grid interoperability compliance.

- (Others standards bodies- IEEE 1547.6, IEEE P2030, IEEE P1901, UL2208, NEC part 625…..)

Reference Slide





Modular EVSE functionality

Could be pass-through, or full function

(from SAE proposal)

Layer Definitions;

Layer 1= PHY

Layer 2= MAC, etc

Hardware Interoperability

- Demonstrating hardware interoperability requires additional communication between the EVSE and the utility AMI infrastructure.
- Though ZigBee communication using Smart Energy Profile (SEP 2.0) is assumed for most of the SAE development work, the utility HAN standards offer Home Gateway as an alternative for utility communication.
- The home gateway solution will integrate electric vehicle as one of the home appliances monitored and controlled as part of the home energy management system.

2) Universal Metropolitan Area Network Radio

- Develop capabilities for single chip 'software defined radio' (SDR) in VHDL programming language, based a matrix of transistor gates known as a Field Programmable Gate Array (FPGA). The PHY (layer 2) specifications defined by IEEE 802.15.14 (zigbee), IEEE 802.15.14c/d (China and Japan version) and IEEE 802.15.14g (under development).
- The radio can operate in one of the modulation modes: FSK, MPSK, Q-QPSK and OFDM in multiple bands including 314-316MHz, 430-434MHz, and 778-787MHz.
- Universal Metropolitan Area Network (U-MAN) sub-MHz frequency range listed here for different countries has better signal penetration through buildings than typical 2.4GHz WiFi or Zigbee wireless.
- Integrate SDR- based UMAN radio into EVSE modular communications port and validate functionality with HMI.

3) Compact EVSE Metrology

- Investigate state of the art voltage and current sensor technology presently used in utility grade ‘Smart meter’ devices, with cost, accuracy, physical sensor volume required for these devices and robustness.
- Benchmark and investigate off-the-shelf alternative current sensor technologies such as Rogowski coils and related integrator signal conditioning electronics.
- Develop innovative planar geometry flux gate magnetometer that measures the magnetic field associated with current flowing through existing conductors in the EVSE without a traditional bulky and fragile torroidal ferrite core.
- Develop analog signal conditioning integrated circuit that may allow this sensor technology to be more compact than tradition sensors today.
- Develop and validate compact metrology system that inputs various analog sensors to generate digital data stream to wireless communications equipment in task #2.

4) Integrate Home Gateway w/ AMI

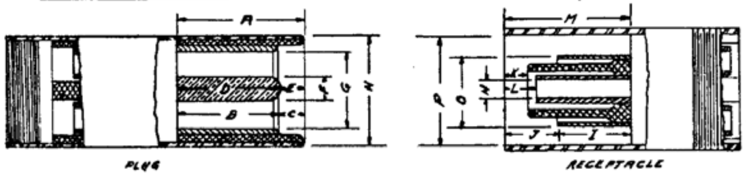
- Work closely with experts in state of the art execution of IEEE 802.15.4 (Zigbee) such as DTE Energy Meter Lab, to integrate electric vehicle supply equipment (EVSE) to Zigbee communication on electrical utility meter deployed Advanced Metering Infrastructure (AMI).
- Subcontract development of a Home Area Network (HAN) compliant gateway that allows messages to pass from the vehicle to EVSE to Utility or home network communications equipment via IPv6. (harmonized with GITT Project 2 software).
- Define testing procedures to validate functionality of Home Gateway network with other system components and test environments, such as higher electromagnetic interference (EMI) exposure
- Set up evaluation test bench at DTE Meter Lab for Home Gateway Interoperability Testing
- Investigate interoperability of Home Gateway with existing EVSE manufacturers' products

Connector Standards- 1913 with 30,000 EVs in

Electric Vehicle Association of America

124 W. 42ND ST.
NEW YORK

Standard Charging Plugs and Receptacles.



contacts must be accurately concentric to insure interchangeability.

* Capacity	A	B	C	D	E	F	G	H	I	J	K	L	M	Machined N	Swaged N	Machined O	Swaged O	P
50 AMP	1 15/16	1 9/16	9/8	1 5/8	5/16	.373 .375	1.125 1.127	1.725	1 1/8	7/8	3/8	3/8	2	.375 .377	.360 .365	1.123 1.125	1.136 1.140	1 3/4
150 AMP	2 3/8	1 9/16	13/16	2 1/16	5/16	.435 .437	1.406 1.408	2.100	1 13/32	1 5/16	5/16	7/16	2 3/32	.437 .439	.422 .427	1.404 1.406	1.416 1.421	2 1/8

* The National Board of Fire Underwriters have approved plugs of the above dimensions for these ratings with an allowable overload of 50%.

Polarity— Outside contact positive, inside contact negative.

Terminals—Should be large enough to receive cable having a rating, according to the Underwriter's Code "Table B," at least equal to the normal rating of plug.

Terminals are to be marked + and – to correspond to polarity of contacts as above.

COMMITTEE ON STANDARDS
E.R. Whitney. Chairman.
Alexander Churchward.
J.R.C. Armstrong.
H.H. Rice.
W.E. Holland.
E.J. Ross Jr
E. Gruenfelt.
Charles Blizzard.
J.H. Hertner.
Louis Burr

Dec 10th 1913

Recommended by Standardization Committee and accepted by E.V.A.A. Oct. 1912 and Oct 1913.

The electric vehicle - raising the standards

Figure 3.25: 150 A charging plug with handle[101]

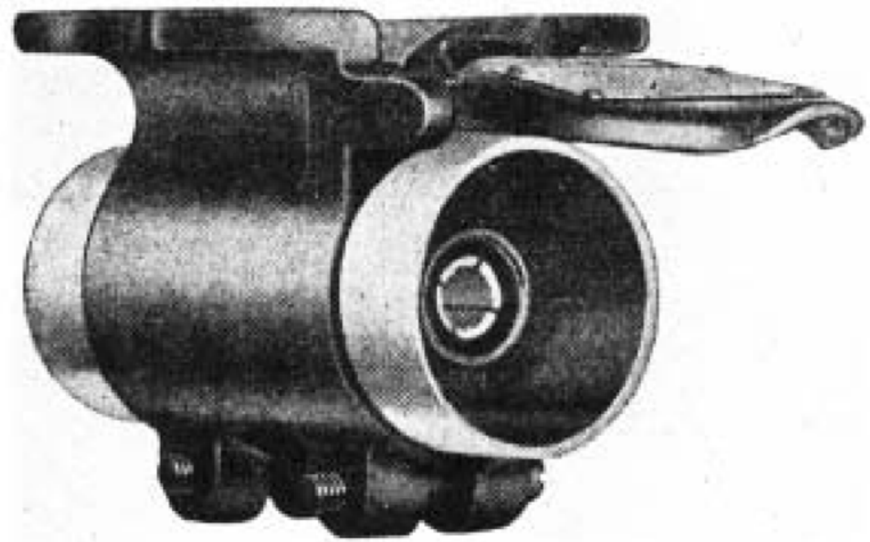


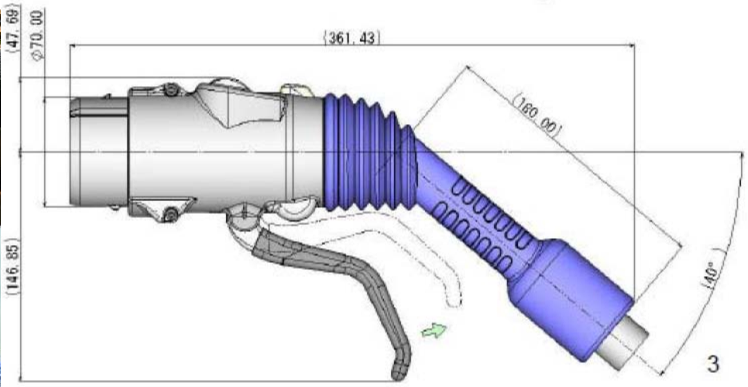
Figure 3.26: 150 ampere-hour (sic) charging receptacle[102]

JARI/TEPCO 50kW Connector

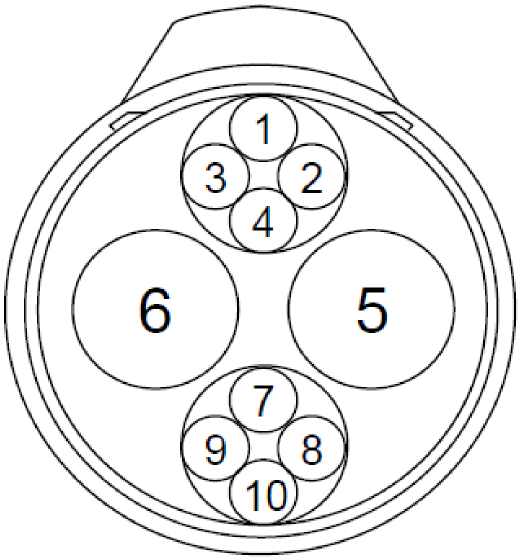
57 Chargers in service in Japan and 1,000 chargers are scheduled to be installed by 2012.

Charger Specifications

- **Input: 3-phase 200V**
- **Maximum DC output power:** **50kW**
- **Maximum DC output voltage:** **500V**
- **Maximum DC output current:** **125A**

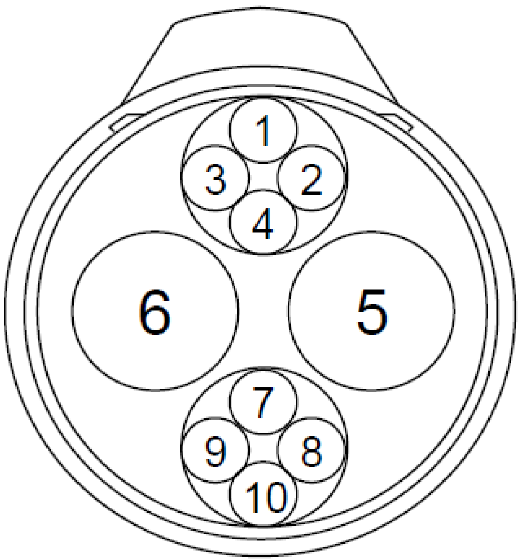


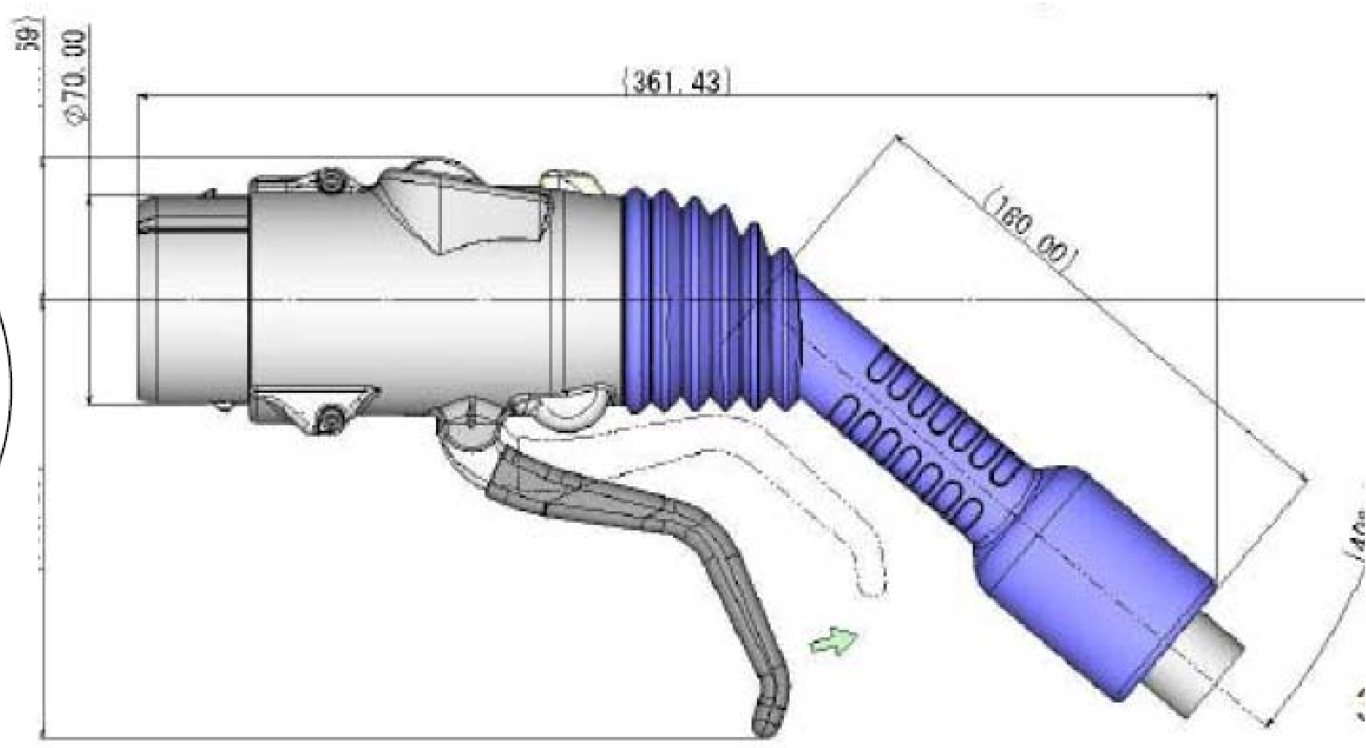
5 minute charge for 40km (25 miles) driving range
10 minute charge for 60km (37 miles) driving range



- Two power; seven control/communication pins
- Two communication pins （typically CAN).
- Two pins for EV relay control.
- One Reference Ground pin for vehicle isolation monitor.
- One proximity or mating detection pin.
- One "ready to charge" pin.

TEPCO Connector Dimensions





70mm dia vs 44mm for SAE version

JARI 200A compared to 1772™ Combo

Amphenol

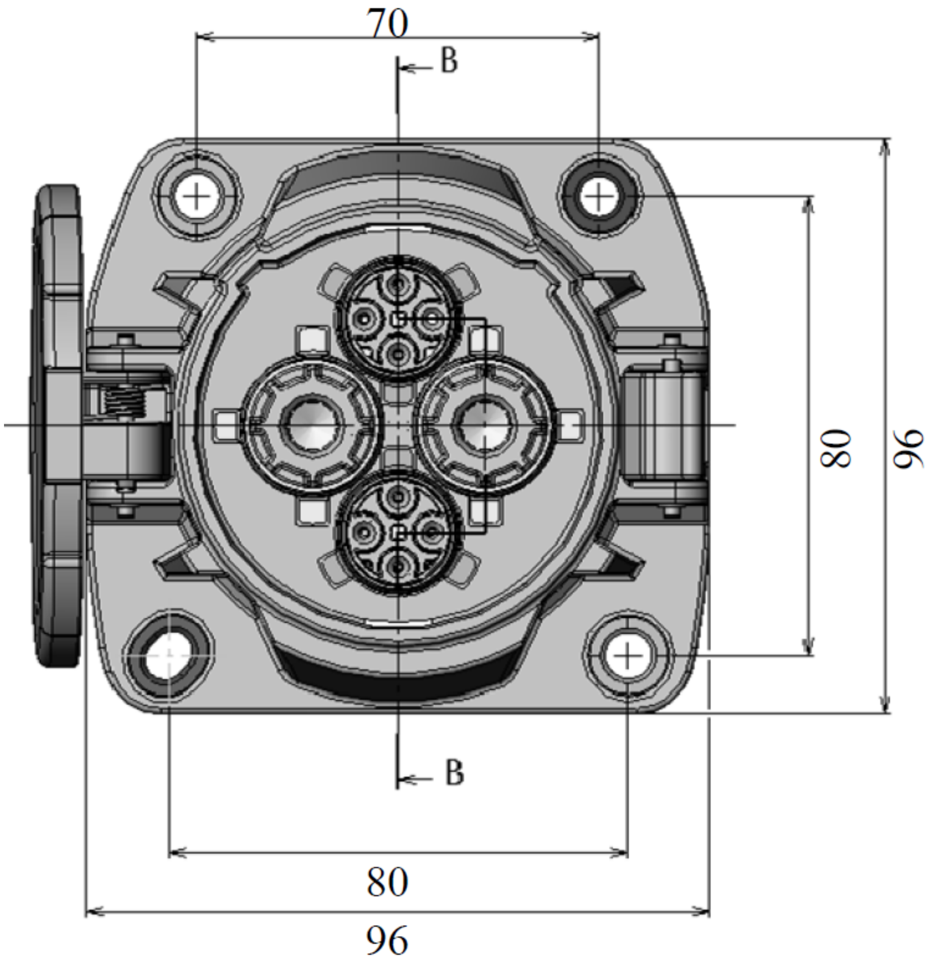
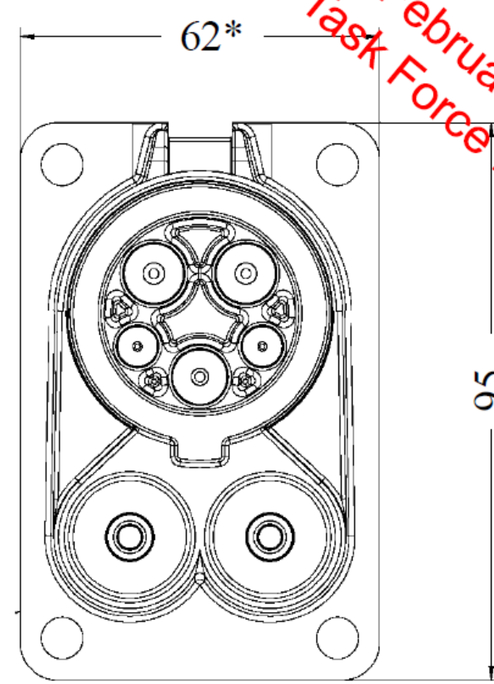


Image from Yazaki 200A DC presentation to SAE J1772™ workgroup, Oct 2009.



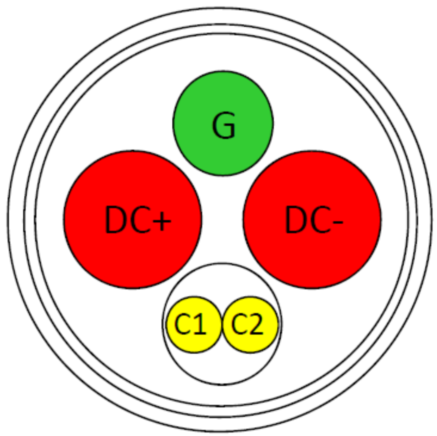
*Note: Amphenol preliminary design does not include provisions for hinged cover, will require additional x-dim size. Expected width similar to Yazaki inlet (left).

UL2251 Charge Cord for 200A

Amphenol

February 2010
Task Force Meeting

200A J1772™ DC Cable



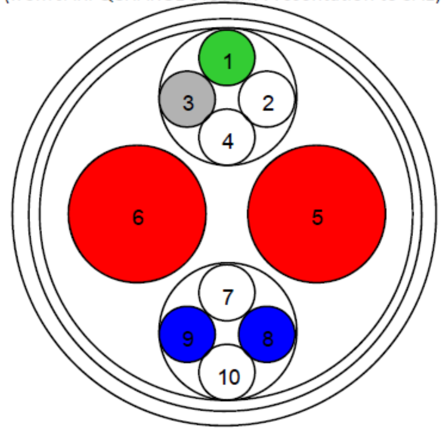
Pin No.	function /role
G	6AWG Ground
DC+	Power (supply) line -positive
DC-	Power (supply) line -negative
C1	Control 1
C2	Control 2

Cable w/6AWG ground will be approx **7%** heavier than JARI cable.

- Power cables define cable OD in both cases
- 1/0AWG copper wire is 0.48 kilograms/meter
- 6AWG copper wire is 0.12 kilograms/meter
- 18AWG copper wire is 0.007 kilograms/meter

200A JARI Cable

(from JARI QCHARGE SYSTEM Presentation to SAE)



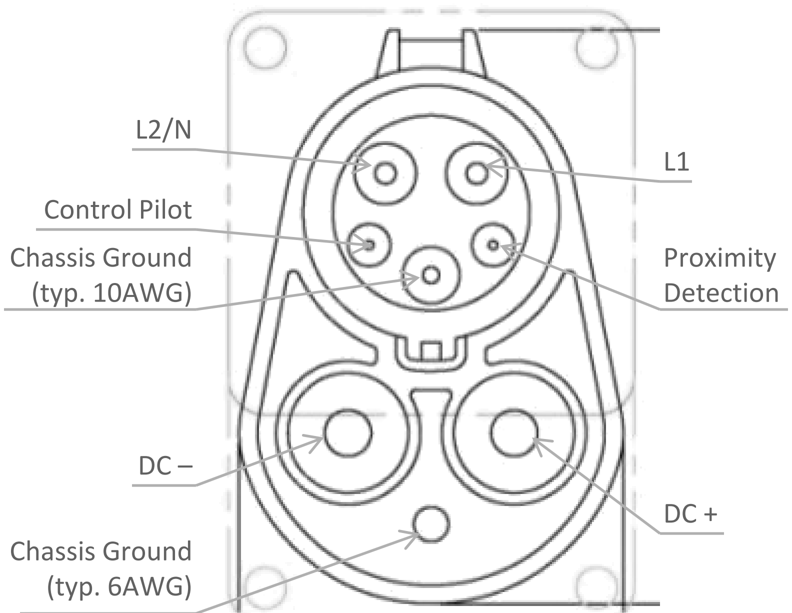
Pin No.	function /role
1	Reference GND for insulation monitor
2	Control EV relay (1 of 2)
3	(not assigned)
4	Ready to charge control
5	Power (supply) line -negative
6	Power (supply) line -positive
7	Proximity detection
8	Communication +
9	Communication -
10	Control EV relay (2 of 2)

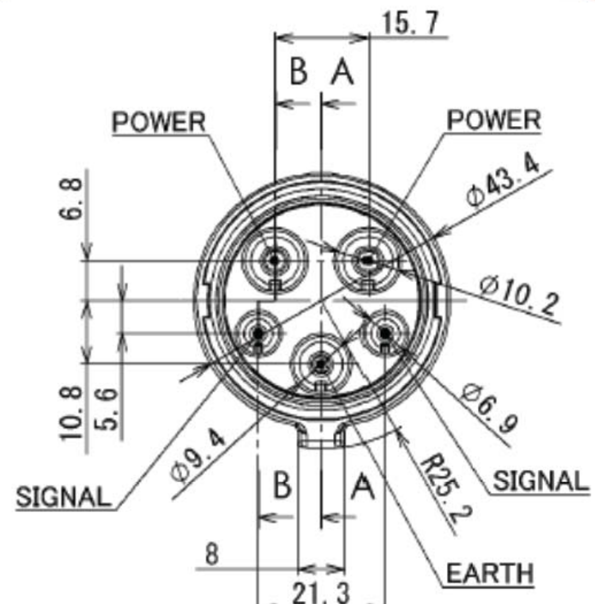
SAE J1772™ Standards- 2010

5 pins total:

- Single phase pwr 2 pins power (80A)
- ground
- pilot signal (pwm current cmd)
- proximity

Proposed AC+DC Coupler

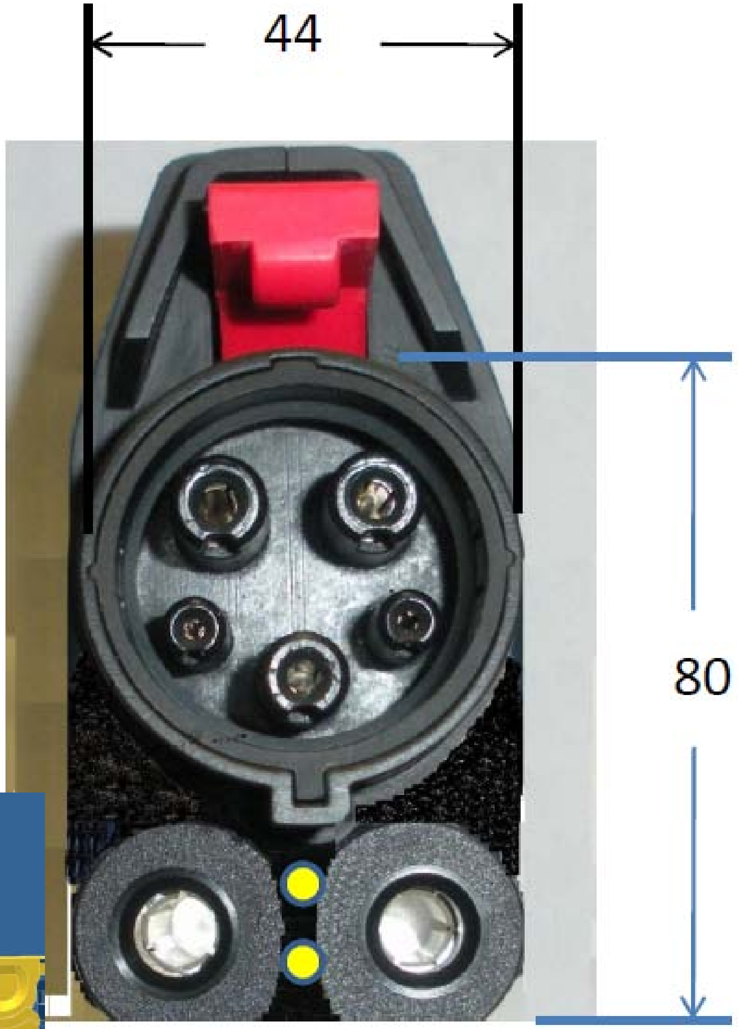


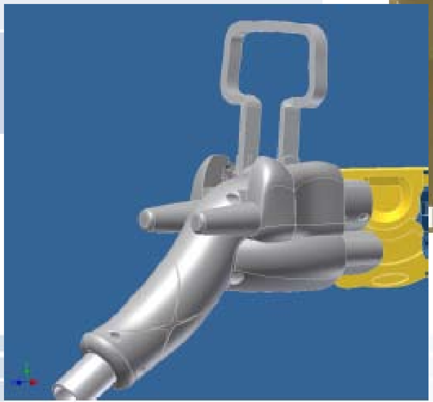


- EVSE sets Control Pilot duty cycle to 5%
- PLC communications is established; Vehicle and EVSE exchange parameters (e.g. HV bus measurements, isolation status and state of S3 (closed))
- Vehicle activates latch lock (optional for AC Level 1&2, required for DC)

March J1772™-DC Standards Updates - *DRAFT*

Preliminary Specifications		
Voltage	600 VDC	
Current, DC	200 A	
Contacts	DC Power	8.0 mm diameter
	Ground	2.8 mm diameter
	Signal	1.5 mm diameter
Cable Sizes	DC Power (2)	AWG 1/0 (50 mm²)
	Ground (1)	AWG 6 (15 mm²)
	Signal (4)	AWG 18 (0.75 mm²)
Ingress Protection		IPX5
Weight Estimate, including 7.5m cable & mechanical assist		10.75 Kg (23.7 Lbs.)
Insertion / Extraction Force With Mechanical Assist		< 60 N





Rema/Amphenol Proposed Format

SAE J1772™ DC *Hybrid* Inlet

Amphenol

Standard AC Level II Inlet Geometry

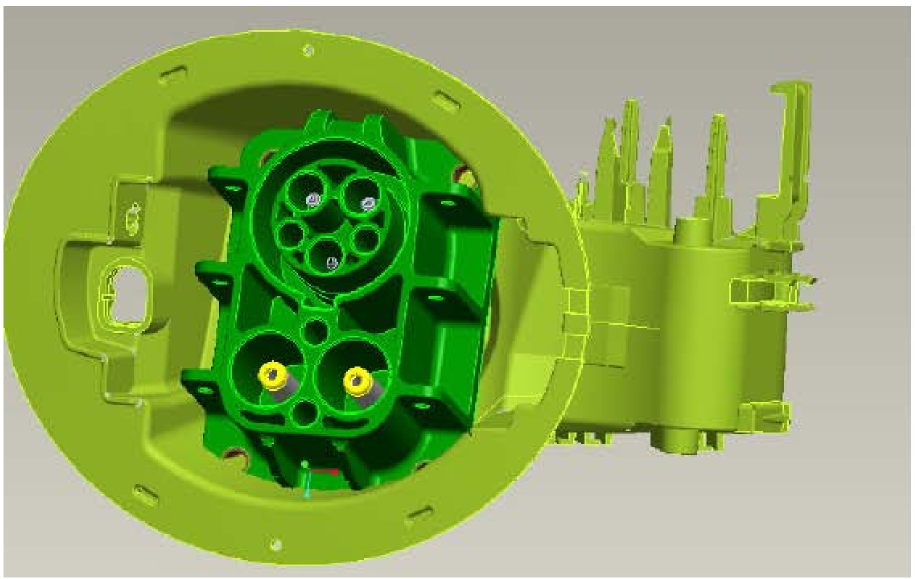
8.0mm DC Contacts, IP2X Touchproof, 1/0awg Crimp

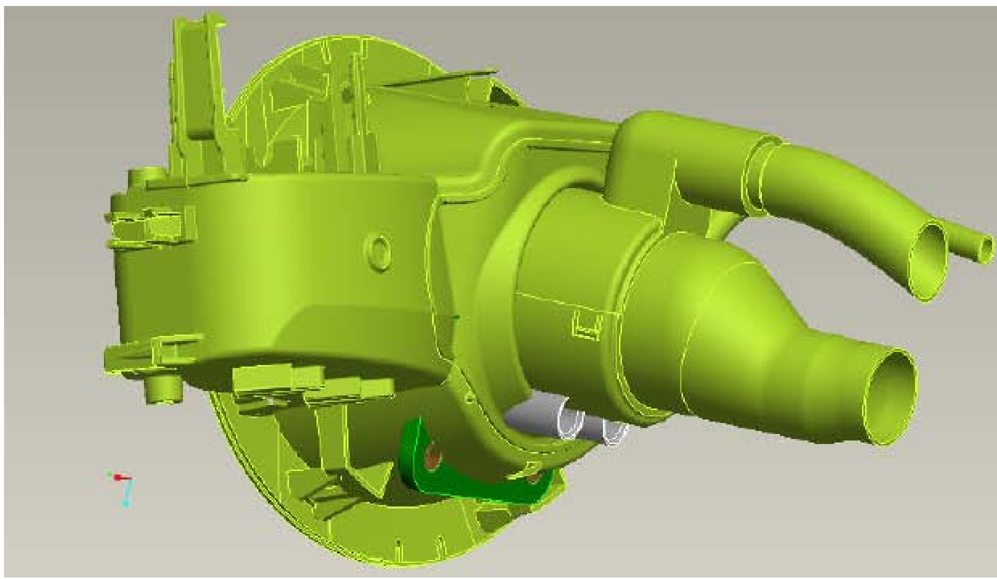
Existing 2.8mm Ground contact will be modified to accept 6awg cable *only* on DC Combo couplers

Current design has CAN terminals in 12 and 6 o'clock positions for better protection.

Project on track for combined design review presentation by REMA/Amphenol end of April 2010.

Rendering in mid-sized vehicle fuel inlet

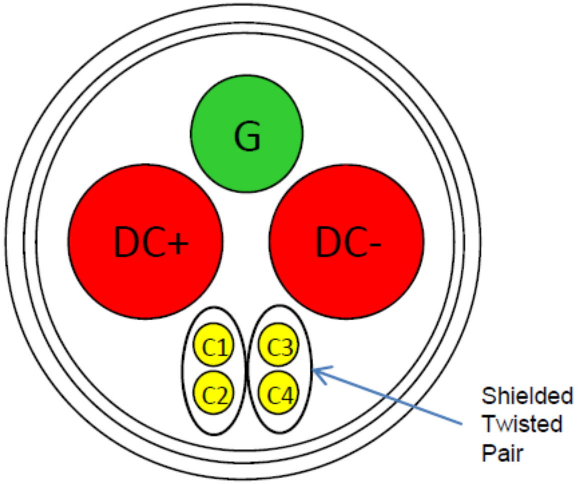




UL2251 Charge Cord for 200A

Amphenol

200A J1772™ DC Cable
w/CAN twisted pair



- Power cables define cable OD in both cases
- 1/0AWG copper wire is 0.48 kilograms/meter
- 6AWG copper wire is 0.12 kilograms/meter
- 18AWG copper wire is 0.007 kilograms/meter

Pin No.	function /role
G	6AWG Ground
DC+	Power (supply) line -positive
DC-	Power (supply) line -negative
C1	Control 1
C2	Control 2
C3	CAN_HI
C4	CAN_LO

Can we use flexible (corrugated) conduit with loose individual conductors (DC+, DC-, GND) and shielded twisted pairs for signals? Improves flexibility/weight and reduces min lot charges and leadtimes for custom constructed cords.

SAE J1772™ –DC (Amphenol slides)
Accommodate isolated or non isolated EVSE DC supply