

*EVS29 Symposium
Montréal, Québec, Canada, June 19-22, 2016*

The AVTE Interoperability Project: Phase 1, AC Conductive Charging

Rich Byczek¹, Dr. Jeffrey Wishart²

¹*Intertek, 45000 Helm St, Suite 150, Plymouth Twp, MI 48170, rich.byczek@intertek.com*

²*jeffrey.wishart@intertek.com*

Summary

This discussion will review the goals and progress of the Dept of Energy AVTE(Advanced Vehicle Testing and Evaluation) program, the current status of ongoing programs and potential upcoming projects. This will include focus on EV charging issues, such as the recent completion of the SAE J2953 EVSE Level 2 interoperability study, and challenges related to DC Fast Charging.

1 Introduction

1.1 AVTE Program

The Advanced Vehicle Testing and Evaluation (AVTE) program is a DOE-funded (\$33.4M, 80/20 cost share), 7-year effort that is part of the Advanced Vehicle Testing Activity (AVTA), with the objective to test advanced vehicles and associated infrastructure that help reduce U.S. petroleum consumption. The project is managed by Idaho National Laboratory. Intertek's Center for the Evaluation of Clean Energy Technology (CECET), located in Phoenix, is the testing partner

Results of the AVTA/AVTE activity are posted on the AVTA website [1]

1.2 EVSE Interoperability Program

The first objectives of the Interoperability Project were to conduct a series of tests as part of an evaluation of the Society of Automotive Engineers (SAE) International J2953™ standard and to assist the SAE J2953™ committee in finalizing the standard. The standard will be used to determine the interoperability of plug-in electric vehicles (PEVs) and electric vehicle supply equipment (EVSE) unit pairs that are SAE J1772™ compliant. By testing different combinations of PEVs and EVSE units, insights can be gained into how potential inconsistencies in adherence to the SAE J1772™ standard by either the PEV or EVSE can affect vehicle charging.

2 Testing Approach

2.1 SAE J2953/1, /2 [2], [3]

Testing procedures used for this study were defined within the draft version of the SAE J2953 standard.

2.2 Core Related Standards

2.2.1 SAE J1772 [4]

The SAE J1772 standard provides the core design requirements for AC and DC Conductive charging. This standard is the basis for the individual requirements within the SAE J2953 Standard and testing program. SAE J1772 includes physical parameters, specifically the mating couplers between the EVSE and electric vehicle for conductive coupling. Secondly the standard provides the core interface circuitry requirements to provide the required voltages and signal parameters for the Control Pilot and Proximity Detection interfaces. Finally, the standard provides the functional protocol to initiate, sustain and complete a charging event. Within the AC Charging portions of the standard, both AC Level 1 and AC Level 2 conditions are defined. For the purposes of this study, AC Level 2 was chosen as the most commonly available in the public domain for both permanent home installations or public/ municipal charging stations. These stations utilize the 5-pin connector defined within the standard and operate at a voltage of 208 to 240 VAC, with a maximum continuous charging current of 80 ADC. AC Level 1 refers to systems operating at a voltage of 120VAC and 16 ADC maximum charging current. At the time of developing this study, most of the AC Level 1 systems available in the public domain were those provided with each Electric Vehicle, and therefore the concern of public domain interoperability was not considered.

2.2.2 UL 2251/CSA C22.2 No. 282-13/ NMX-J-678-ANCE-2013 [5]

The UL 2251 tri-national (USA, Canada, and Mexico) standard provides electrical safety requirements for the conductive mating couplers between the EVSE and electric vehicle. Although the most common AC conductive coupler in the US market is based on the SAE J1772 design, UL 2251 is protocol agnostic, and rather defines safety related criteria of the mechanical interface. For the purpose of the SAE J2953 study, all EVSE used were verified to incorporate NRTL (Nationally Recognized Testing Laboratory) certified couplers, as part of a certified EVSE.

2.2.3 UL 2594/ CSA C22.2 No. 280-13/ NMX-J-677-ANCE-2013 [6]

The UL 2594 tri-national (USA, Canada, and Mexico) standard provides electrical safety requirements for Electric Vehicle AC Charging Stations. Much like UL 2251, it is protocol agnostic, but includes requirements for the Control Pilot and Proximity Detection functions defined in SAE J1772. For the purpose of the SAE J2953 study, all EVSE used were verified to be NRTL (Nationally Recognized Testing Laboratory) certified systems.

2.2.4 IEC 61851-1 [7]

The IEC 61851 series of standards provides a harmonized (to SAE J1772) set of protocol requirements in terms of Control Pilot and Proximity Detection interfaces. The -21 and -22 portions provide specific safety and functional requirements for both the EVSE and electric vehicle to complete AC Charging events. This standard series has been adopted in the European Union, and is based on the available voltages and phases in the EU public domain. Therefore, while the interface protocols are largely harmonized to the US-based standards and SAE J1772, they assume different connectors, operating voltages, and protection devices than US-based safety standards. For this reason, the IEC 61851 series was not specifically considered when selecting EVSE or vehicles for the SAE J2953 study.

2.2.1 IEC 62196-1 [8]

The IEC 62196 series of standards provides a set of coupler requirements for AC Charging, in accordance with IEC 61851. The -2 part of the standard provides specific requirements for the AC Charging coupler/ interface. This includes the SAE J1772 AC Charging coupler as one of multiple configurations. However, as this standard is not adopted in North America, it was not considered in selection of EVSE and electric vehicles for this study.

2.3 Selection of EVSE and Vehicles

SAE International, one of the partners in this interoperability study, was tasked with soliciting test vehicles from the automotive OEMs, as well as AC Level 2 EVSE from the various manufacturers who provide NRTL-certified EVSE to the US market. In all, 11 OEMs provided a total of 14 vehicles, and 12 EVSE manufacturers provided a total of 14 AC Level 2 EVSE. In the cases when an OEM provided 2 vehicles, one vehicle was a BEV (Battery Electric Vehicle), having no additional motive power source beyond the battery, and the other vehicle was a PHEV (Plug-in Hybrid Electric Vehicle), incorporating both an internal combustion engine along with a traction power battery. In cases when an EVSE manufacturer provided two EVSE, one of the EVSE was a home-installation version, and the other a public/commercial installation version. The list of participants may be found in Table 1.

Table 1: Vehicle and EVSE Participants

Vehicles (OEM and Model)	EVSE (Mfr. and Model)
BMW i3	AddEnergie CoRe+
Chevrolet Volt	AddEnergie Smart Two
Fiat 500e	Aerovironment EVSE-RSW30B15CXXW-0001
Ford Focus EV	Bosch AWU70217BEN-B
Ford Fusion Energi	ChargePoint CT 4020-HD-GW
Honda Accord PHEV	Clipper Creek CS-100
Honda Fit EV	Clipper Creek LCS-25
Kia Soul EV	Eaton Marina EVSE L230CNBW
Mitsubishi i-MiEV	EVSE LLC Watt Point
Nissan Leaf	GE Wattstation
Smart fortwo ED	Merit Charge ergl-01
Toyota Prius Plug-in	Schneider-Electric EV230WS
Toyota RAV4 EV	Siemens VersiCharge
VW e-Golf	Telefonix L1x2

2.4 Test Tiers

2.4.1 Tier 1

Tier 1 testing focused on core functionality of the EVSE/EV interaction and successfully initiating, conducting and completing a charge event. These tests consisted of mechanical interface and connector insertion force measurements, basic charge functionality (sequencing through the various charging states), and Core safety functionality (time in milli-seconds, required to remove live voltages from the EVSE/EV interface.)

2.4.2 Tier 2

Tier 2 testing focused on grid events and power quality issues. Various voltage and frequency fluctuations are introduced at the input of the EVSE, and observations are made of any reactions or abnormal operation of the EVSE or vehicle during and after each Tier 2 event.

2.4.3 Tier 3

Tier 3 tests focused on optional features of the EVSE or EV related to charging. Specifically, these test focused on the implementation of delayed or scheduled charging times.

2.5 Test Equipment and Setup

The testing was conducted at Intertek's Plymouth Twp, MI facility. 14 different vehicles from 11 different vehicle OEMs, and 14 different Level 2 AC charge stations from 12 different EVSE manufacturers were selected and provided for this study by each EV or EVSE manufacturer.

3 Test and Report

3.1 Test Results

In total, over 2,500 individual test were performed, consisting of 3 tiers of tests, and by pairing each vehicle with all 14 of the available EVSE (196 vehicle/EVSE combinations). Each EVSE manufacturer and each vehicle OEM were provided a detailed report of all test results for their specific product or vehicle. Overall results and observations were anonymized and reported publicly via Idaho National Laboratories. [9]

3.1.1 Tier 1 Test Results

A total of 664 Tier 1 pairings and individual conditions were tested. A summary of results may be found in Table 2.

Table 2: Tier 1 Test Summary

Tier 1 Test	Pass	Soft Pass	Pass+, Soft Pass+	Soft Fail	Fail	Incomplete	Feature
Mechanical							
• Connect	113	8	N/A	3	47	N/A	N/A
• Disconnect	127	5	N/A	6	20	N/A	N/A
Charge Functionality	31	124	3	N/A	0	N/A	13
Safety Feature Functionality	22	120	N/A	N/A	0	12	13

3.1.2 Tier 2 Test Summary

A total of 1573 Tier 2 pairings and individual conditions were tested. A summary of results may be found in Table 3.

Table 3: Tier 2 Test Summary

Tier 2 Test	Pass	Soft Pass	Fail	Timer	Comm	Exception
Indefinite Grid Event						
• Voltage Swell	53	82	28	0	0	0
• Voltage Sag	59	104	0	0	0	0
• Frequency Swell	58	96	0	0	0	0
• Frequency Sag	51	112	0	0	0	0
Dynamic Grid Event						
• Voltage Swell	25	81	1	0	0	43
• Voltage Range Variation	42	120	0	0	0	4
• Voltage Sag	28	109	0	0	0	0
• Momentary Outage	34	79	3	5	3	35
• Long-Term Outage	14	75	2	14	6	47
• Frequency Range Variation	54	103	0	0	0	0

3.1.3 Tier 3 Test Summary

A total of 262 Tier 3 pairings and individual conditions were tested. A summary of results may be found in Table 4.

Table 4: Tier 3 Test Summary

Tier 3 Test	Pass	Soft Pass	Fail	Exception	Pass*, Soft Pass*
Scheduled Charge					
• PEV Scheduled Charge	56	29	4	N/A	N/A
• EVSE Scheduled Charge	11	11	4	N/A	N/A
Staggered Schedule Charge					
• PEV Scheduled First	6	6	3	N/A	N/A
• EVSE Schedule First	6	6	3	N/A	N/A
Charge Interrupt & Resume					
• PEV Interrupt	0	0	0	4	46
• EVSE Interrupt	0	0	0	3	52
Ampacity Control	0	0	0	N/A	N/A

3.2 Observations

Several of the tests and pairings resulted in “Soft Pass” conditions. By soft pass, either the EVSE or EV did not comply with some aspect of the SAE J1772 protocol, however the charging event was able to occur. The mechanical tests were found to have some repeatability concerns, and recommendations to refine this particular test were provided to the SAE J2953 committee.

3.2.1 Tier 1 Key Observations

During the tier 1 mechanical tests, it was noted that the force measurement fixture could not produce easily reproduceable measurements, due to the complex angles involved with properly seating the coupler into the vehicle receptacle. This fixture design should be further developed and added as a recommended figure within the SAE J2953 standard. Within the study, each of these mechanical measurements was repeated for

a total of 10 iterations for each vehicle pairing to provide more repeatable average results. Additionally, the use of SOFT PASS, and SOFT FAIL results are used here to note the instances when, upon multiple iterations of the same test, there was a mixture of passing and failing results. For example, a SOFT PASS for the Connect test would indicate that majority of iterations met the criteria of <75 Newton insertion force.

3.2.2 Tier 2 Key Observations

In the Tier 2 testing, many “SOFT PASS” events were noted. In this instance, SOFT PASS refers to some expected portion of the measured result (a timing interval, specific interim step voltage or other parameter) was not met, but the lack of that parameter did not prevent the charge event from occurring (i.e. Interoperability was achieved, although either/both the EVSE and/or vehicle did not meet certain criteria). These criteria and related tolerances may need to be reviewed for further development of the standard and tier 2 test criteria.

3.2.3 Tier 3 Key Observations

In the Tier 3 testing, several of the EVSE or vehicles did not incorporate such optional features as delayed or scheduled charging, and therefore the total number of tests was reduced, compared to Tier 1 and Tier 2. Additionally, and similar to Tier 2 test results, some instances resulted in a SOFT PASS, where some portion of the test criteria was not met, but the charge event was able to occur as scheduled or programmed.

4 Next Steps

4.1 This Study

Results of this study are under review by the SAE J2953 committee for potential changes to the J2953 standard. Additionally, observations of the functionality of test equipment and data acquisition, as provided by Argonne National Laboratories, was provided to Argonne for potential revision of the test equipment used to conduct this and further related studies.

4.2 Stage 2, DC Fast Charge

The next stage of this study is to conduct a similar EVSE/EV pairing test, using DC Fast Charge type, also per the SAE J1772 protocol. Additional considerations are being made for inclusion of other technologies for DC fast charge, such as Chademo-compliant or Tesla’s Supercharger systems. At the time of this paper, Stage 2 testing program has not yet been fully defined or scheduled.

Acknowledgments

U.S. Department of Energy, Vehicle Technologies Office

Idaho National Laboratories, AVTA Activity

SAE International

References

- [1] <http://avt.inl.gov>
- [2] SAE J2953/1 (issued 2013-10-12) Plug-In Electric Vehicle (PEV) Interoperability with Electric Vehicle Supply Equipment (EVSE), SAE International, www.sae.org
- [3] SAE J2953/2 (issued 2014-1-22) Test Procedures for the Plug-In Electric Vehicle (PEV) Interoperability with Electric Vehicle Supply Equipment (EVSE), SAE International, www.sae.org

- [4] SAE J1772 (issued 2012-10-15) SAE Electric Vehicle and Plug in Hybrid Electric Vehicle Conductive Charge Coupler, SAE International, www.sae.org
- [5] UL 2251 (2/22/2013) Standard for Plugs, Receptacles, and Couplers for Electric Vehicles, Underwriters Laboratories, www.comm-2000.com
- [6] UL 2594 (2/22/2013) Standard for Electric Vehicle Supply Equipment, Underwriters Laboratories, www.comm-2000.com
- [7] IEC 61851-1 (2010-11-25) Electric vehicle conductive charging system - Part 1: General requirements, International Electrotechnical Commission, www.iec.ch
- [8] IEC 62196-1 (2014-6-19) Plugs, socket-outlets, vehicle connectors and vehicle inlets - Conductive charging of electric vehicles - Part 1: General requirements, International Electrotechnical Commission, www.iec.ch
- [9] <http://avt.inl.gov/evse.shtml>

Authors

Rich Byczek is the global technical lead for electric vehicle and energy storage at Intertek. He has 20 years of experience in product development and validation testing, 12 of which have been spent at Intertek. Rich is also an expert in the areas of energy storage, audio equipment and EMC. Rich sits on several SAE, IEC, UL and ANSI standards panels. He holds a Bachelor of Science in Electrical Engineering from Lawrence Technological University in Southfield, Michigan, and is based at the Intertek facility located in Plymouth, Michigan.

Dr. Jeffrey Wishart is an Engineering Team Lead with the Intertek Center for Evaluation of Clean Energy Technology. He has over 10 years in the advanced vehicle research area, focusing on powertrain technologies that increase efficiency and reduce petroleum consumption and infrastructure that enables plug-in electric vehicles. Dr. Wishart is also an expert on fuel cell systems and hydrogen technologies.. Dr. Wishart holds a Ph.D. in Mechanical Engineering from the Institute for Integrated Energy Systems (IESVic), University of Victoria, as well as a Master of Science in Engineering Physics from the University of Saskatchewan and a Bachelor of Applied Science in Engineering Physics (with a Mechanical Engineering Minor) from the University of British Columbia.