

Development and Implementation of SAE J2953 for AC Charging

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ABSTRACT

The purpose of this paper is to outline the development and implementation of SAE J2953. SAE J2953 contains the requirements and procedures of interoperability testing. Within SAE J2953 interoperability test articles are defined as an Electric Vehicle Supply Equipment (EVSE) paired with a Plug-in Electric Vehicle (PEV). SAE J2953 requires the development and application of test fixtures with the ability to monitor mechanical forces and electrical signals of a charge system without modification or disassembly of the EVSE and PEV under test. Electrical signal monitoring includes pilot, proximity, and line conductors of the SAE J1772 TM AC coupler. This paper will outline the requirements of the fixtures as well as a specific build. Data will be presented showing full implementation of the SAE J2953 procedures including root-cause analysis and standards gap discovery.

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INTRODUCTION

Plug-in Electric Vehicle (PEV) is a class of vehicle that relies on the use of a rechargeable energy pack to drive or contribute to the drive of a vehicle's powertrain. PEV refers to a superset of vehicles that include plug-in hybrid electric vehicles (PHEV), battery electric vehicles (BEV), and extended range electric vehicles (EREV). While the PEV is partially depleted of its charge it is configured to be recharged with the use of Electric Vehicle Supply Equipment (EVSE). The SAE J1772 standard defines a common PEV and EVSE conductive charging method including operation requirements and the functional and dimensional requirements for the vehicle inlet mating connector. [1] SAE J1772 defines charge methods for AC level 1 and AC level 2, as well as DC level 1 and DC level 2. For the purpose of this paper only AC level 1 and level 2 charging will be covered.

The SAE J1772 coupler is a conductive coupler that consists of a PEV inlet and an EVSE connector. The PEV inlet contains 5 core pins: AC Power (L1), AC Power (L2/N), Equipment Ground, Control Pilot, and Proximity Detection. The EVSE connector consists of 5 corresponding sockets. There are 3 circuits that are realized when the PEV inlet is coupled with an EVSE connector, these 3 circuits include: Mains Charge Circuit, Control Pilot Circuit, and Proximity Detection Circuit.

The Mains Charge Circuit consists of the L1, L2/N, and Equipment Ground conductors. This is the circuit that the PEV uses to transfer power from the supply grid to its rechargeable energy pack. The EVSE is connected to the supply grid and typically implements a set of contactors that open and close depending on the PEV readiness to charge. The Mains Charge

Circuit on the PEV side is connected to the PEV on-board charger. The on-board charger rectifies the AC power to deliver a DC charge to the energy pack.

The Control Pilot Circuit is the primary control circuit. Communication between the EVSE and PEV occur by measuring the physical parameters of a pulse width modulated signal that is induced by the EVSE on the Control Pilot conductor. EVSE state is controlled by either inducing a modulated signal on the control pilot conductor or maintaining a steady voltage. During modulation the EVSE communicates supply current capacity by modulating the Control Pilot circuit at a certain duty cycle. The charge system state is controlled by the PEV. The PEV can increase or reduce resistance on the Control Pilot circuit in order to control the peak voltage of the Control Pilot circuit. With these parameters the EVSE and PEV are designed to safely setup, maintain, and complete a charging session.

The Proximity Detection circuit is designed to allow the PEV to detect the presence of an EVSE charge connector coupled to the PEV inlet. The EVSE connector is outfitted with a latch tied switch that modifies the Proximity Detection circuit when the connector latch is not in the latched position. With this feature the PEV can tell if the EVSE connector is both coupled and latched properly. Only the PEV is required to monitor the Proximity Detection circuit for AC charging.

Utilizing these circuits an AC level 1 EVSE is able to charge a PEV at 120V_{RMS}, single phase, and less than 16A_{RMS}. An AC level 2 EVSE is capable of charging at 208V_{RMS} or 240V_{RMS}, single phase, at less than 80A_{RMS}.

SAE J2953 AC INTEROPERABILITY

SAE J2953 has been developed in order to define the requirements (J2953/1) and procedures (J2953/2) to ensure that a PEV - EVSE pair is interoperable. J2953 claims that EVSE and PEV conformance to J1772 does not necessarily ensure PEV - EVSE interoperability. J2953 defines a test article as a PEV-EVSE pair.

Interoperability, as defined in SAE J2953, is the “capability of a standards conforming device to function as intended with other standards conforming devices without special effort by the user.” [2] By extension of this definition J2953/1 compiled a series of charge system requirements based upon SAE J1772 that defined how an EVSE and PEV must interact at the coupler interface. These requirements pertain to the Mains Charge circuit, Pilot Control circuit, and Proximity Detection circuit. The J2953/1 requirements can be separated into 6 major sections: (1) Start-up Sequence timing, (2) Control Pilot voltage, (3) Control Pilot Waveform parameters, (4) Shutdown Sequence timing, (5) Proximity Detection voltage, and (6) Error Handling timing.

SAE J2953/1 also defines 3 different degrees of interoperability for AC PEV charging. A tiered system approach is used to test for fatal PEV charging flaws as well as minor nuisances that reduce functionality of unique PEV or EVSE features. Tier 1 testing ensures the most essential functionality while Tier 2 and Tier 3 testing includes incrementally less essential functionality. Table 1 is a test list that breaks down the 3 tiers of interoperability and the tests associated with each tier. Tier 1 tests focus on basic functionality, Tier 2 is used to gauge the robustness of a charge system under un-ideal conditions, and finally Tier 3 tests are used to check non-standard feature functionality.

Table 1. Depiction of how the various AC interoperability testing fits into the J2953/1 defined interoperability tiers.

Tier	Test
1	Mechanical Interoperability
	Charge Functionality
	Safety Feature Functionality
2	Indefinite Grid Events
	Dynamic Grid Events
3	Ampacity Control
	Scheduled Charge
	Staggered Scheduled Charge
	Charge Interrupt/Resume

SAE J2953/2 contains the guidelines and procedures for interoperability testing. In order to conduct thorough, non-evasive testing SAE J2953 requires testing to be conducted using a breakout fixture in tandem with data acquisition devices and data logging system. Figure 1 shows a generic interoperability test setup. With this setup, a test operator can easily measure the status of a charge system's Control Pilot, Proximity Detection, and Mains Charge circuit. Since the breakout fixture is designed to connect to existing EVSE and PEV connecting equipment it does not require any modification to the PEV and EVSE hardware.

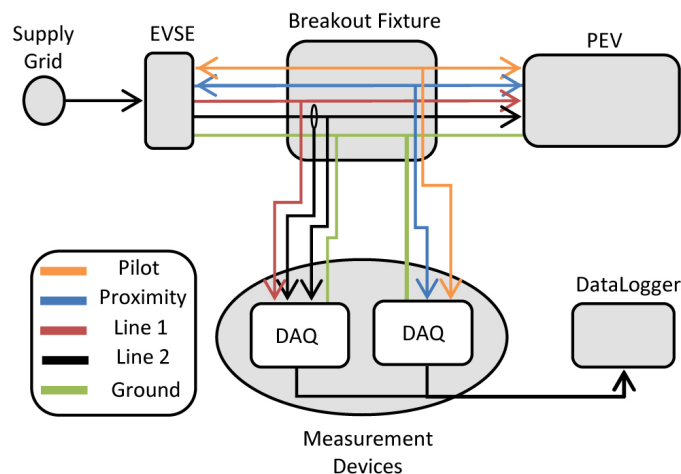


Figure 1. SAE J2953/2 Test Procedures Setup allows for system level analysis that gives insight on component interactions. Non-evasive design makes setup and testing easy to perform.

The breakout fixture is a tool used for all tiers of testing. It must be made custom to accommodate measurement devices that will be used by the operator during testing. The tool is designed to pass through all line and signaling conductors between the EVSE and PEV while being able to breakout the conductor nodes for measuring by the data acquisition and data logging system. It is required that the fixture does not break any of the line or signaling circuits to the measurement equipment; i.e. the measurements must be in parallel, not series.

Figure 2 is a sample image of a breakout fixture. Required features include UL listed SAE J1772 inlet and connector. Inlet, connector and all conductors must be rated for voltage and current limits exceeding the capabilities of all EVSE and PEV articles to be tested. The J1772 connector requires modification such that it does not terminate the proximity circuit, rather it is to pass the proximity conductor through the breakout fixture and ultimately to the EVSE connector for termination.

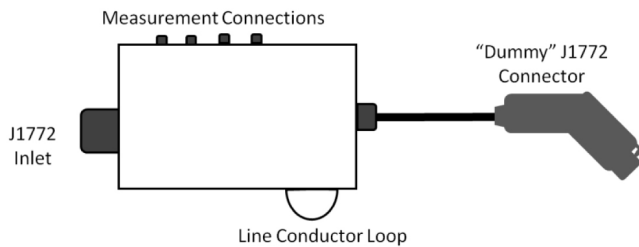


Figure 2. Interoperability breakout fixture is custom designed to interface specific data acquisition tools with an AC PEV charge system.

SAE J2953 AC INTEROPERABILITY TESTING IMPLEMENTATION

Hardware Overview

Argonne National Laboratory has designed an interoperability test system in order to evaluate and validate SAE J2953/1 interoperability requirements and SAE J2953/2 test procedures. Figure 3 shows the complete system in a bench-top form. The core of the fixture, pictured at the base of the mobile cart, is a pass through box that is equipped with a J1772 charge inlet and charge connector. The pass-through box functions as the breakout box and also contains data acquisition hardware that will be covered in the next section. An Agilent oscilloscope, pictured on the middle shelf, monitors the oscillating control pilot circuit and serves data on frequency, duty cycle, and rise/fall times to the LabView loaded PC (top-shelf). The PC is outfitted with custom LabView virtual instruments that are designed to interface with the data acquisition devices to collect and log the data.

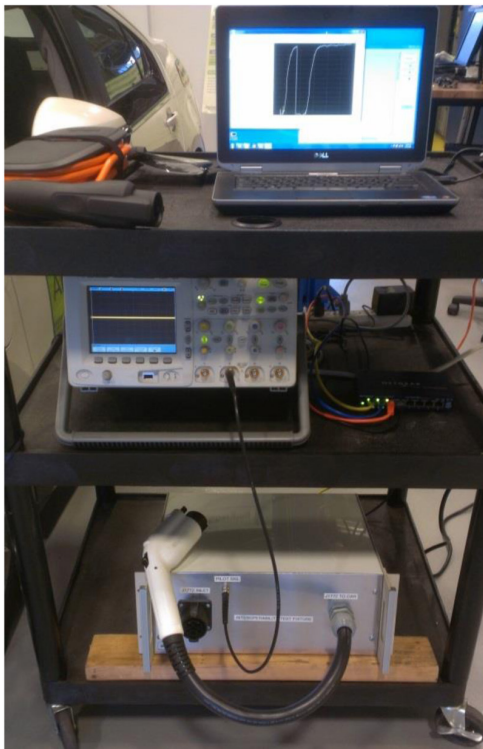


Figure 3. Argonne's Interoperability test system is custom designed to test an EVSE-PEV pair to SAE J2953 AC interoperability requirements.

Breakout Fixture and Data Acquisition Overview

The breakout fixture is the core of the AC Interoperability test system. The fixture peripherals are all located on the front and rear panels. The front panel includes an 80 Amp rated SAE J1772 inlet identical to those found on SAE conforming PEVs. A similarly rated SAE J1772 cord set with plug is also found at the front of the fixture. This plug is modified such that the proximity detection circuit has been removed from it. Instead the plug is made to pass the proximity detection conductor through the fixture back into the previously mentioned J1772 inlet. This is done so that the PEV proximity detection circuit can be coupled with the EVSE proximity detection circuit. Finally, the front panel contains a BNC connector that is connected by low capacitance coaxial cable to the Agilent oscilloscope. The coaxial cable carries the control pilot signal to the oscilloscope. The oscilloscope measures the rise time, fall time, and settling time of the control pilot during oscillation.

The back panel of the breakout fixture only contains a power cable that feeds the internal power supply and a RJ-45 jack that is used to interface the real-time controller to the PC.

Internally the breakout fixture is more complex. It is most important to first note the high voltage and low voltage terminal blocks mounted to the side of the fixture (purple). These allow for the pass-through of all SAE J1772 conductors from EVSE to PEV. The National Instruments cRIO system (green) is comprised of four pieces of equipment. NI CRIO-9081 LX75 is an embedded monitoring tool that contains a dual-core processor, and 8-slot FPGA chassis that can be outfitted with various modules. For AC interoperability testing purposes the CRIO 9081 is outfitted with 3 NI modules (orange). NI 9221 is an 8-channel $\pm 60V$ 12-bit Analog Input module. Only two channels are used; one for proximity detection circuit monitoring and one for control pilot monitoring. NI 9225 3-channel 300Vrms 24-bit Analog Input module is used to monitor the voltage of the mains charge circuit. The last module utilized is the NI 9227 4-channel $\pm 5A$ 24-bit Analog Input module. It is used in tandem with the 80-5 current transformer (yellow) to monitor the current flow of the mains charge circuit.

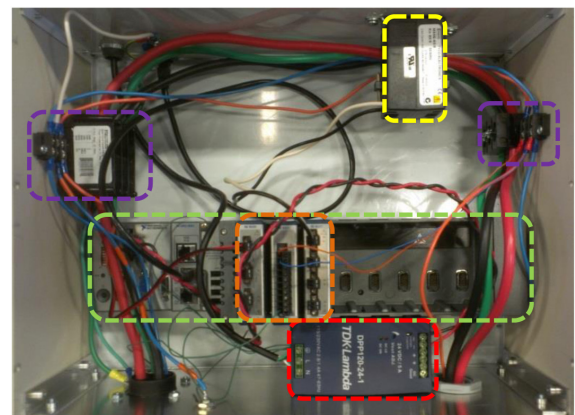


Figure 4. Argonne's Interoperability test system breakout fixture internals.