



SURFACE VEHICLE RECOMMENDED PRACTICE

J2894/2

MAR2015

Issued

2015-03

Power Quality Test Procedures for Plug-In Electric Vehicle Chargers

RATIONALE

In 2011 SAE issued power quality requirements for plug-in electric vehicle (PEV) chargers in response to rising sales of PEVs and concerns about their potential impact on utility systems and on other devices connected adjacent to them. Electrical power is delivered upon demand, and utility systems are impacted by demand, or power, and the duration of that demand. Distinctions must be made about real power, which does work, and apparent power, which is the impact on the electrical system. The integration of transportation and the electric grid imposes concerns about not only serving demand and making sure that not only are existing deliveries made, but the additional load of vehicle chargers as well. Utilities must work to ensure reliability and quality of service. Computer equipment and controls are impacted negatively by distortions such as harmonics, so PEV chargers, like most all electronics, must limit potentially disruptive effects. In addition to impacts of equipment on the grid, the equipment itself must be reliable and effective when presented with effects impressed upon it, as can occur with the wide variety of loads and conditions that could emerge on the modern grid. Therefore, criteria were established to ensure that PEV charging equipment could continue to operate after encountering such grid events. These recommendations were presented in SAE J2894/1, *Power Quality Requirements for Plug-In Electric Vehicle Chargers*. This recommended practice provides the test procedures for measuring the criteria.

Since the power quality recommended practice was issued, interest has emerged for measuring and regulating energy efficiency of battery charging systems, on state and federal levels. Battery chargers have historically only been judged for efficiency instantaneously on a power conversion basis, as battery charging systems also include a battery, which is a variable energy reservoir, and a vehicle with auxiliary systems and controls. However, recent efforts have established energy efficiency measurement methods based on a systems approach. With these methods, grid energy input is measured against useful output. As there is not yet clear direction on things like "allowable" auxiliary loads, this recommended practice maintains the measurements in separate bins and provides suggested limits.

FOREWORD

With a growing and rapidly changing electric grid system, electrical equipment suppliers are being required to provide equipment which complies with increasingly stringent requirements. Environmental concerns, economics, and technology have combined to cause change and anticipated change in a short amount of time that is almost unprecedented. Similar forces that have led to PEVs have led to renewable energy sources, in both centralized generator form and as distributed power producers. The increased load on the system to fuel PEVs must be served by a more diverse, less consistent supply. SAE J2894/1 established a recommended practice for key parameters that are of concern to supply PEV charging systems. However, those key parameters cannot be used to communicate with manufacturers, suppliers, and energy providers without a means for determining them. This Recommended Practice provides those means.

SAE Technical Standards Board Rules provide that: "This report is published by SAE to advance the state of technical and engineering sciences. The use of this report is entirely voluntary, and its applicability and suitability for any particular use, including any patent infringement arising therefrom, is the sole responsibility of the user."

SAE reviews each technical report at least every five years at which time it may be revised, reaffirmed, stabilized, or cancelled. SAE invites your written comments and suggestions.

Copyright © 2015 SAE International

All rights reserved. No part of this publication may be reproduced, stored in a retrieval system or transmitted, in any form or by any means, electronic, mechanical, photocopying, recording, or otherwise, without the prior written permission of SAE.

TO PLACE A DOCUMENT ORDER: Tel: 877-606-7323 (inside USA and Canada)
Tel: +1 724-776-4970 (outside USA)
Fax: 724-776-0790
Email: CustomerService@sae.org
<http://www.sae.org>

SAE WEB ADDRESS:

Full document details: [SAE J2894_2_201503](http://www.sae.org/technical/standards/J2894_2_201503)

SAE values your input. To provide feedback
on this Technical Report, please visit
http://www.sae.org/technical/standards/J2894/2_201503

Documents

Document Sharing Hub

The information presented in this Recommended Practice may be used by charging system designers, PEV designers, managers of charger development programs, and electric utilities.

NOTE: This SAE Recommended Practice is intended as a standard practice and is subject to change to keep pace with experience and technical advances.

NOTE: This SAE Recommended Practice involves testing procedures that may present potential safety hazards. For safety instructions refer to local, state, and federal regulations including, but not limited to, OSHA Standard 29 CFR 1910 subpart S.

TABLE OF CONTENTS

1.	SCOPE	3
2.	REFERENCES	5
2.1	Applicable Documents	5
2.2	Other Publications	6
3.	DEFINITIONS	6
3.1	SAE J2894/1 Definitions Listed for Reference	6
3.2	Additional Definitions	7
4.	PROCEDURES	8
4.1	Instrumentation	8
4.2	Uncertainty Requirements	9
4.3	Test Guidelines	9
4.4	Test Setup	10
4.5	Charger Power Quality Test	11
4.6	AC Service Event Test	16
4.7	Energy Efficiency Measurements	23
5.	ENERGY EFFICIENCY PARAMETERS	26
6.	DATA SHEET	27
7.	TEST FLOW CHART	35
8.	NOTES	36
8.1	Marginal Indicia	36
Figure 1	Power quality system boundary (on-board charger)	3
Figure 2	Power quality system boundary (off-board)	4
Figure 3	Power quality EVSE system boundary (with test tool)	4
Figure 4	Sample AC charging profile	12
Figure 5	Sample power conversion efficiency curve	12
Figure 6	Diagram of system setup	17
Figure 7	Voltage range variation test	18
Figure 8	Voltage swell test	19
Figure 9	Voltage sag test	20
Figure 10	Momentary outage test	20
Figure 11	Energy efficiency discharge system boundary	23
Table 1	Uncertainty requirements	9
Table 2	Resolution requirements	9
Table 3	Energy efficiency input power requirements	11
Table 4	Example of test points for 240V on-board system	17
Table 5	Frequency variation steps	21

1. SCOPE

This recommended practice provides test procedures for evaluating PEV chargers for the parameters established in SAE J2894/1, *Power Quality Requirements for Plug-In Electric Vehicle Chargers*.

In addition, this Recommended Practice provides procedures for evaluating EVSE/charger/battery/vehicle systems in terms of energy efficiency, which is a subset of power quality. This expansion of scope from J2894/1 was requested by the stakeholders, and it provides relevance to the system level analyses that are current in state and federal processes. In accordance, the scope includes the energy storage system and the input and output of that system.

In consideration of evaluation, a system boundary is established. The system boundary defines the tested elements and the measurement points. The system boundary for most of the systems expected to be evaluated under this Recommended Practice is shown in Figure 1. In this system boundary the parts of the battery charging system that are included for evaluation are the EVSE, the battery charger (BC), the system powering auxiliary loads, and the battery. It should be noted that this is a change from the original text of J2894/1, but it was essential for the purposes of system analysis to include all the elements, such as the EVSE, to evaluate efficiency and response to events. In terms of power quality and efficiency, the effects of this change should be minor. Note that no distinction is made about the battery or the auxiliary loads, which may include fans, chillers, or other thermal management devices. Note that some systems may require multiple measurement points to capture all auxiliary loads.

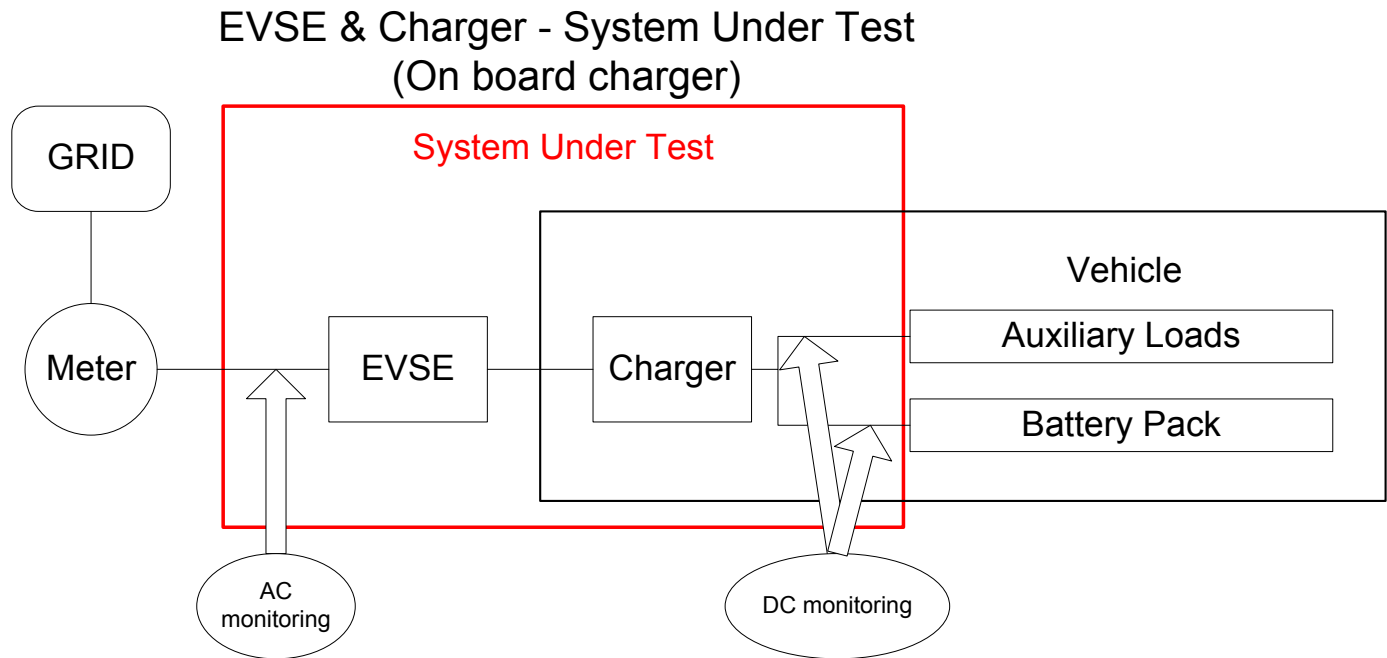


Figure 1 – Power quality system boundary (on-board charger)

Figure 2 shows the system boundary for an off-board charging system.

EVSE & Charger - System Under Test (Off board charger)

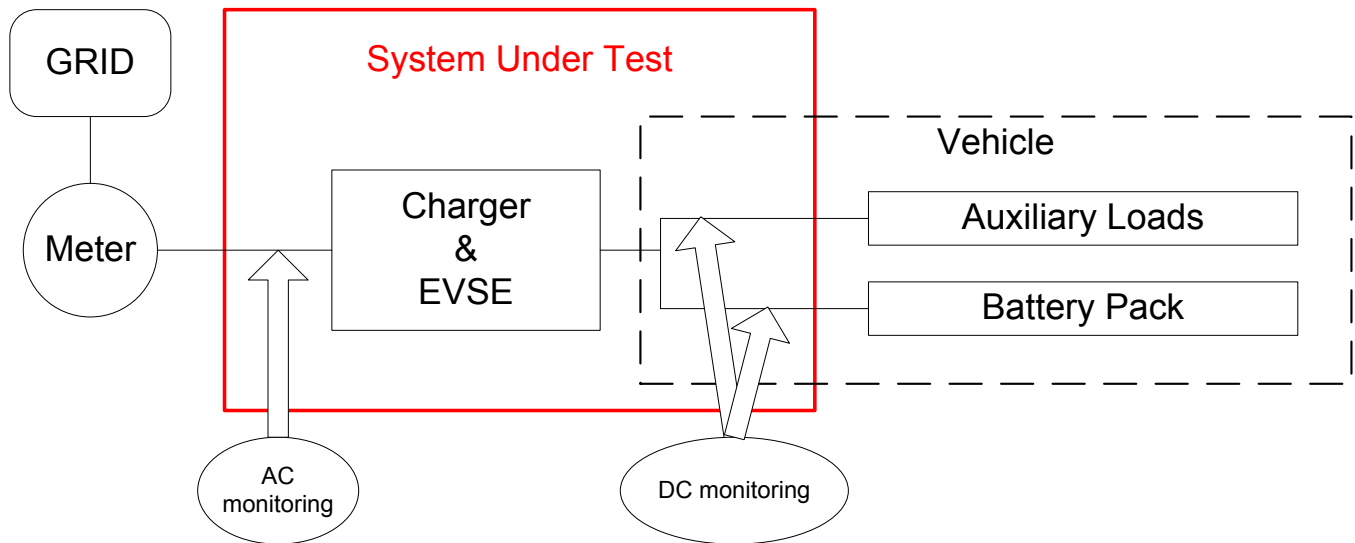


Figure 2 – Power quality system boundary (off-board)

Figure 3 shows the special case of an EVSE under test with a testing tool.

EVSE - System Under Test (Test Tool)

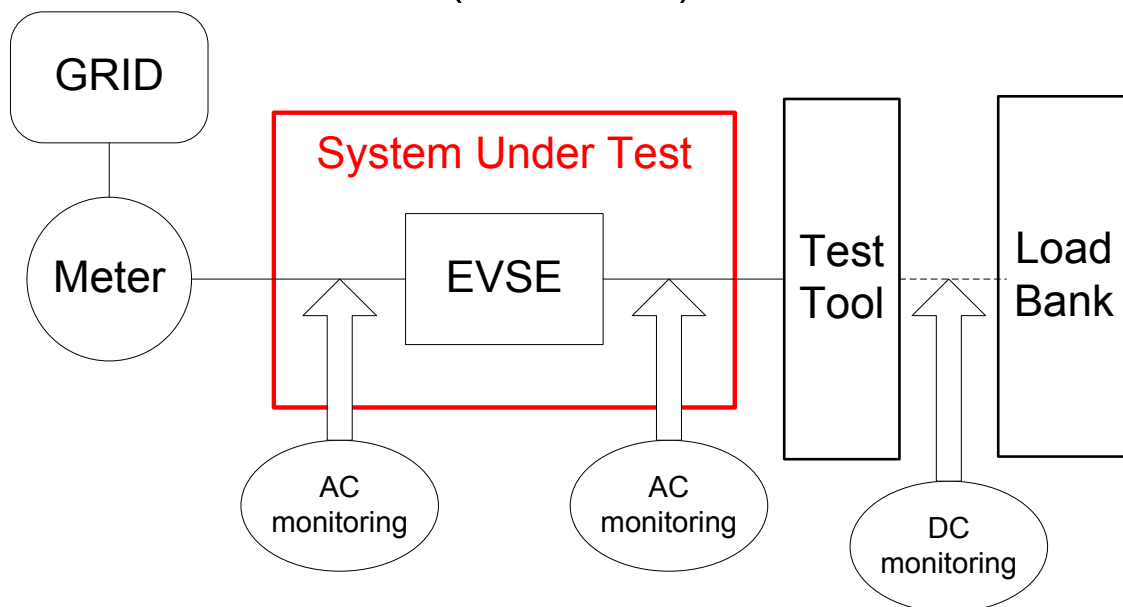


Figure 3 – Power quality EVSE system boundary (with test tool)

Note that all systems include an EVSE device. EVSE devices can introduce variance in test results. Therefore, all system test results must be recorded for, and are only valid for the tested combinations.

Auxiliary loads include all of the separable electrical loads on the vehicle while charging and discharging that are necessary for safe and effective operation and sufficient battery life, but are separate from energy going into the battery that later does work.

Examples of auxiliary loads:

- Control modules
- Active battery cooling and heating system components
- Data systems or telematics
- Cabin comfort systems
 - Cooling
 - Heating
- 12V system support (charging auxiliary, or starting, battery)

2. REFERENCES

2.1 Applicable Documents

The following publications form a part of this specification to the extent specified herein. Unless otherwise indicated, the latest issue of SAE publications shall apply.

2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or 724-776-4970 (outside USA), www.sae.org.

SAE J1772 SAE Electric Vehicle and Plug in Hybrid Electric Vehicle Conductive Charge Coupler

SAE J2894/1 Power Quality Requirements for Plug-In Electric Vehicle Chargers

2.1.2 International Electrotechnical Commission Publications

Available from IEC, 3 rue de Varembé, PO Box 131, CH – 1211 Geneva 20 – Switzerland, Tel: 41-22-919-02-11, www.iec.ch

IEC 61000-4-5 International Electrotechnical Commission, Electromagnetic compatibility (EMC) – Part 4-5: Testing and measurement techniques – Surge immunity test, IEC 61000-4-5, Edition 2.0, 2005-11.

IEC 61000-3-2 Limits for Harmonic Current Emissions

IEC 61000-3-3 Limits for Voltage Fluctuation and Flicker

IEC 61000-4-4 Electrical Fast Transient/ Burst Immunity

IEC 61000-4-5 Surge Immunity

IEC 61000-4-11 Voltage Dips, Short Interruptions and Voltage Variation Immunity

IEC 61000-4-13 Harmonics and Interharmonics Immunity

IEC 61000-4-14 Voltage Fluctuation Immunity

IEC 61000-4-28 Variation of Power Frequency Immunity

IEC 62301 Household electrical appliances – Measurement of standby power

2.1.3 National Electrical Manufacturers Association Publications

Available from NEMA, 1300 North 17th Street Suite 1752 Rosslyn, VA 22209, Tel: 1-703-841-3200

National Electric Code (NEC), 2011 revision

2.1.4 Underwriters Laboratories Inc. Publications

Available from Underwriters Laboratories Inc., 333 Pfingsten Road, Northbrook, IL 60062-2096, Tel: 1-847-272-8800, www.ul.com

UL 2231-1 Personnel Protection Systems for Electric Vehicle (EV) Supply Circuits: General Requirements

UL 2231-2 Personnel Protection Systems for Electric Vehicle (EV) Supply Circuits: Particular Requirements for Protection Devices for Use in Charging Systems

UL 2202 Electric Vehicle (EV) Charging System Equipment

2.2 Other Publications

USABC Electric Vehicle Battery Test Procedures Manual, Rev. 2, (DOE/ID-10479, Rev. 2, Jan. 1996)

Energy Efficiency Battery Charger System Test Procedure, Version 2.2, November 12, 2008, CEC, Part 2

Test Procedures for Battery Chargers and External Power Supplies, 10 CFR Part 430, 1JUN2011

3. DEFINITIONS

3.1 SAE J2894/1 Definitions Listed for Reference

3.1.1 AC Level 1 Charging

3.1.2 AC Level 2 Charging

3.1.3 Charger

3.1.4 Charger – Isolated

3.1.5 Charger – Non Isolated

3.1.6 Charger – Inductively Coupled

3.1.7 DC Charging

3.1.8 Electric Vehicle Supply Equipment (EVSE)

3.1.9 Frequency Variation

3.1.10 Momentary Outage

3.1.11 On-Board Charger

3.1.12 Off-board charger

3.1.13 Voltage range

3.1.14 Voltage sag

3.1.15 Voltage surge (Transient)

3.1.16 Voltage swell

3.2 Additional Definitions

3.2.1 Active mode

Active mode is defined by the state when all of the following are true:

- a. Power is being supplied to the battery charging system by the utility
- b. The battery charger is supplying power to the battery
- c. The effect of power supply is to change the battery state of charge (SOC) from a lower SOC to a higher SOC

3.2.2 Battery maintenance mode

Maintenance mode is defined by the conditions of:

- a. Power is being supplied to the battery charging system by the utility
- b. Active mode has been completed but the connections maintained

Maintenance mode may be characterized by continuous or periodic power delivery periods, the purpose of which is to compensate for self-discharge, provide thermal management, perform system checks, or other maintenance activities. This recommended practice measures maintenance mode over 72 hours.

3.2.3 Charge return factor

The ratio of the Ah delivered to the battery during the recharge cycle to the Ah delivered by the battery during the discharge cycle.

3.2.4 Energy return ratio (ERR)

The energy input into the system to restore it to the state preceding a standard battery discharge (which could have provided work) divided by the energy delivered by the battery discharge. The inverse of this ratio is a measure of a type of system energy efficiency.

$$ERR = \frac{AC_{in} \text{ kWh}}{DC_{out} \text{ kWh}}$$

3.2.5 No-battery energy

The energy consumed by the battery charging system when in no-battery mode.

3.2.6 No-battery mode

No-battery mode is defined by the conditions of:

- a. Power is being supplied to the battery charging system
- b. The part of the system containing the battery has been disconnected

An example of an on-board system would be an EVSE, powered but with no PEV connected and an example of an off-board system would be a fast charger, powered, but with no PEV connected.

3.2.7 Off mode

Off mode is defined by the condition that the entire system is connected, power is being supplied, but there is no output from the charger because the charger is switched off. If there is no off switch then this mode is not applicable. This mode applies to the EVSE when not connected to on-board chargers, or off-board chargers not connected to a vehicle.

3.2.8 Off mode - asleep

Off mode is defined by the condition that the entire system is connected, power is being supplied, but there is no output from the charger because the charger is asleep (or timed out to an asleep mode) and this mode should be a very low power state compared to active mode. In this mode a user would need to activate the charger via a button or other signal. This mode applies to the EVSE when not connected to on-board chargers, or off-board chargers not connected to a vehicle.

4. PROCEDURES

4.1 Instrumentation

The following devices may be needed for the tests: Every piece of equipment involved in measurements must be calibrated and NIST traceable and be within a valid calibration period. Equipment data shall be recorded on the data sheet, including a description, ID number, and the data sampling rate.

- Power quality monitor (example: Dranetz-4400)
 - Current transformers (100A, 30A, 1A, etc.), voltage probes, etc.
- Power quality analyzer (example: Yokogawa PZ4000)
 - Current transformers (100A, 30A, 1A, etc.), voltage probes, etc.
- Digital Scope with multiple input (e.g. Yokogawa DL850)
 - Current transformers (100A, 30A, 1A, etc.), voltage probes, etc.
- Oscilloscope with isolation probes
- DC shunt and metering device
- PEV
- PEV state-of-charge meter (if a PEV is involved in the tests)
- Thermometer
- Barometer
- Humidity Meter
- Timer and/or stopwatch
- Temperature compensated specific gravity meter – used to verify condition and state of charge of a flooded, lead-acid battery
- Advanced Battery Cycler (e.g. ABC-150)
- Voltmeter (V AC, V DC)
- Grid Simulator and Programmable Controller
- Computer
- Isolation test tools (Leakage Current Detector)
- EVSE Test Tool

4.2 Uncertainty Requirements

Measurement methods will not exceed the uncertainty limits presented in Table 1.

Table 1 - Uncertainty requirements

Parameter	Uncertainty	Range
Voltage (V)	$\leq 1\%$	Full Range
Current (A)	$\leq 1\%$	Full Range
Frequency (Hz)	$\pm 1\%$	Full Range
THD (%)	$\pm 2\%$	Full Range
Power (W)	$\leq 2\%$	> 0.5
Power (W)	≤ 0.01	< 0.5
Energy (Wh)	$\leq 2\%$	Full Range
Temperature ($^{\circ}\text{C}$)	≤ 2	Full Range

Data reporting requires the minimum resolution in Table 2.

Table 2 - Resolution requirements

Parameter	Resolution	Range
Power (W)	0.01	< 10
Power (W)	0.1	10-100
Power (W)	1	> 100

4.3 Test Guidelines

This section describes the basic guidelines for setting up the test equipment for power quality parameter tests. This procedure may be conducted just on EVSE and chargers, while skipping energy efficiency measurements, which require a battery. Please note that if performing full energy efficiency testing, start with battery discharge test procedures.

An electrical disconnect switch, inline and in close proximity of the charger, is required for the testing covered by this Recommended Practice.

Properly connect the power quality monitoring equipment to the load side of the disconnect panel that will power the charger. All tests should start with current transformers (CT) of appropriate size. A 40 A breaker should be monitored with a CT rated above 40 A. If a lower current is known to be the maximum for a particular test the CT should be changed to a more appropriately rated CT for that section to improve accuracy.

All data shall be recorded at one minute intervals unless otherwise stated.

If required by the tests, the DC power and energy monitoring device shall be installed at the output of the charger (load side) and DC power converter. There shall be no components or devices inline between the device and its voltage probes. The monitoring device will be of appropriate rating for the output of the charger and power converter.

For all power quality and events tests the battery should be at a state of charge (SOC) of 30% or less, unless otherwise specified.

The test equipment, test apparatus, and test sample must be isolated from each other to ensure that no unintentional ground loops are created by the test setup. The setup must be inspected and approved for personnel and equipment safety.

All data is recorded on the test data sheet.

4.4 Test Setup

4.4.1 Test room

The ambient temperature of the room shall be kept at $25^{\circ}\text{C} \pm 5^{\circ}\text{C}$ from the time that testing begins, including preparation work, until testing is completed. The air speed of the room shall not exceed 0.5 m/s near the test sample and no additional cooling or ventilation shall be provided for the test sample, unless required for safety.

4.4.2 EVSE test tools

Primarily for testing EVSE, a test tool is a device which safely simulates the PEV charge interface. It can have an array of monitoring equipment to perform testing. Some test tools have preprogramed test sets which can produce a formatted report.

4.4.3 Pre test - isolation test

This pre-test determines if the PEV, EVSE and charger are safe and acceptable for use in testing.

4.4.3.1 Vehicle

With the vehicle "off", measure and record the following voltages in the charging receptacle and confirm that they are below 5.0 V:

- Between the main conductors
- Line 1 to ground
- Line 2 to ground
- Line 1 to chassis
- Line 2 to chassis

While the PEV is charging, measure and record the current leakage between the vehicle chassis and earth ground. The current must be less than 3.5 MIU (Measurement Indication Unit, ref. UL 2231).

4.4.3.2 EVSE/charger

With the EVSE/Charger "on," measure and record the following voltages in the charging coupler and confirm that they are negligible (less than 5 V):

- Between the main conductors
- Line 1 to ground
- Line 2 to ground
- Line 1 to chassis
- Line 2 to chassis

4.4.4 Electrical source

This section describes the requirements of the electrical source for the test activities.

Using the grid as the power source, conduct a site evaluation to ensure that the power quality of the site will not affect the test results. The site power quality variation must be limited as follows:

Table 3 - Energy efficiency input power requirements

Voltage (V)	± 3 % of nominal
Frequency (Hz)	± 1 % of nominal
Voltage Total Harmonic Distortion (THD) (%) (up to 13 th harmonic)	≤ 2 %

4.5 Charger Power Quality Test

The tests in this section measure the parameters identified in SAE J2894/1 and help determine the potential impact of the PEV charging system on the utility system.

4.5.1 Power parameters and power conversion efficiency while charging

This test determines the power parameters and power conversion efficiency of the charging system. The test will be repeated at all applicable power levels. The AC source voltage is allowed a tolerance of $\pm 10\%$ for this section.

- Install DC monitoring devices (i.e. shunts) and all measurement equipment as described in the setup section of this procedure.
- Energize the EVSE/charger
- Synchronize the time stamps of the monitoring devices or use a single piece of equipment for all data collection
- Start the monitoring equipment
- Connect EVSE/charger to vehicle and perform a full charge

Record the following at maximum, minimum, and mid-level power:

NOTE: If the charge profile has no distinct minimum power level (less than 5 minutes) then only report the maximum power point. Also if no point for the minimum and middle power can be found within the 5% tolerance do not report those values.

- Displacement power factor
- True power factor (PF)
- Real AC power (W)
- Reactive AC power (VAR)
- Apparent AC power (VA)
- Real DC power to battery (W)
- Real DC power to auxiliary loads (W)
- Voltage total harmonic distortion (THD_V)
- Current total harmonic distortion (THD_I)
- Current distortion at each harmonic frequency