Test Specification – DC Fast Charging at Temperature Testing

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Revision History Log

Revision No.	Revisions Description	Effective Date	Revised By	Approved By
0	Initial release	11/23/2015	Jon Mackie, Jeffrey Wishart, Tyler Gray	Jeremy Diez

Table of Contents

1 Objective

The objective of this Test Specification is to outline the method for testing the direct current (DC) fast charging of the main propulsion energy storage system (ESS) at set temperatures of capable vehicles participating in the Advanced Vehicle Testing and Evaluation (AVTE) program or in other advanced vehicle testing activities. This Test Specification outlines the methods for experimental conduct and data analysis. The actual specific steps for the test conduct are listed and described in the associated Center for Evaluation of Clean Energy Technology (CECET) internal Work Instruction document.

2 Test Conduct

Documentation resulting from usage of this Test Specification shall be consistent, easy to understand, easy to read, and readily reproducible. All documentation required to complete testing shall be completed, approved, and ready for issue prior to commencing the testing it addresses. The following will abide by company policy:

- Review and approval of test results
- Storage and retention of records during and following testing activities
- Recording of any deviation from the outlined procedures and the reason for the deviation

3 Initial Conditions & Prerequisites

Prior to conduct of any portion of the testing, the following initial conditions and prerequisites shall be met. Satisfactory completion of these items should be verified.

3.1 Personnel

Personnel conducting testing under this Test Specification, i.e., the Test or Project Engineer(s), shall be familiar with the requirements of this Test Specification, shall be trained in accordance with company policy, and shall be certified by a Mandated Reviewer prior to commencing any testing activities. This requirement includes training in all aspects of the DC fast charger (DCFC), including its automatic shutdowns and safety procedures.

3.2 Vehicle Modes

All vehicles shall be tested with the ESS state-of-charge (SOC), as indicated by the vehicle energy indicator (VEI) on the vehicle dashboard/or and controller area network (CAN) bus, or all-electric calculated range at the lowest possible value while still assuring driver safety. The manufacturer's user manual should be consulted to provide safe operating practices. Some vehicles may have a "limp home mode" that prevents the vehicle from operating normally when it has reached the low end of the operating capacity of the ESS. If such a mode exists for a particular vehicle, entering it while driving should be considered sufficient for this testing**.**

3.3 Vehicle Conditions

Vehicles to be tested should have an appropriate charging port/connection capable of accommodating the voltage and current required to charge the ESS in one hour or less.

Vehicles should utilize a standardized DC fast charging protocol interface, such as the CHAdeMO™ or SAE J1772™ standards. If no standardized protocol is present, the vehicle manufacturer shall provide or approve the use of a charger that can fully recharge the main propulsion ESS from any state of discharge in less than one hour.

3.4 Environmental Conditions

Charging is to be conducted in a temperature-controlled testing chamber. Testing can take place at any pre-determined temperature. The test chamber shall be capable of averaging an approximate ambient temperature as specified for each test.

3.5 Instrumentation

3.5.1 All instrumentation used during testing shall be calibrated. The calibration shall be performed and documented in accordance with company policy.

3.5.2 All instrumentation shall have the accuracies and resolutions noted. Unless specific exceptions have been made by a Mandated Reviewer, the following identifies the minimum instrumentation specification that shall be installed and employed during the testing.

3.5.2.1 Time

a) Accuracy of ± 0.05 s

b) Resolution of 0.1 s

3.5.2.2 Temperature

a) Accuracy of ± 1 °C (± 2 °F)
b) Resolution of 1 °C (2 °F)
c) The sensing element shall be shielded from heat sources

3.5.2.3 ESS Current

a) Accuracy of ± 1.0 A
b) Resolution of 1.0 A

3.5.2.4 ESS Voltage

a) Accuracy of ± 1.0 V
b) Resolution of 1.0 V

3.5.3 The charge event parameters may be obtained through digital vehicle signals if the accuracy has been validated. Analog signals may also be used. A Mandated Reviewer shall determine what level of instrumentation and data acquisition rates are deemed acceptable. The default acquisition rates for CECET are 100 Hz for non-temperature-based data and 1 Hz for temperature-based data.

3.5.4 The vehicle shall be instrumented with a data logger to capture data the charge event. The data download can be executed through a network or manually per the logger user manual and the data should be inserted into a spreadsheet program for data analysis.

3.5.5 The temperatures inside the chamber such as chamber temperature, vehicle soak temperature and ESS enclosure temperature shall be recorded with a data logger.

4 Test Activity Requirements

This section addresses testing required to meet the stated purpose and objective of this Test Specification.

4.1 Collected Test Data

The following data shall be collected during conduct of the test as specified by this document.

4.1.1 Time (recorded by a data logger):

- Time of day (HH:MM)
- Duration of charge event (s) (initial charge event, interval between initial and top-off, and top-off charge event)

4.1.2 ESS data (recorded by a data logger):

- ESS temperature (°C) (if available)
- ESS SOC (%)
- ESS current (A) and voltage (V)
- ESS charge energy (kWh) (calculated from current and voltage)

4.1.3 DCFC data (manually recorded from the DCFC screen or network, if available):

- Charger-estimated SOC (%) (for reference purposes only)
- Charger DC energy (kWh) (acquired from the DCFC internal energy meter, where available)
- Voltage (A) and current (V) (recorded from the DCFC CAN bus by a data logger for the CHAdeMO protocol only)

4.1.4 Vehicle-calculated data (manually recorded from the vehicle dashboard):

- Vehicle range (mi)
- Vehicle VEI (energy 'bars') (if available)
- Vehicle SOC (%) (if available)
- Ambient temperature (°C)

Data are to be recorded: (1) at beginning of the temperature soak, and (2) at the end of the total charge event.

4.1.5 Temperature data (recorded by a data logger):

- Ambient chamber temperature (°C)
- Vehicle temperature (°C)
- ESS temperature from thermocouple (°C) (if not available from vehicle CAN bus)
- Ambient temperature outside of chamber (°C) (for reference purposes only)

4.2 Test Requirements

4.2.1 Vehicles to be tested should be soaked at temperature in the testing chamber for a minimum of 21 hours. This soak time falls near the middle of the range of time (12 hours to 36 hours) given in SAE J1634 for temperature soaking a battery electric vehicle before range testing.

4.2.2 A vehicle charge is considered complete when the DCFC stops delivering current to the vehicle ESS, and not because of a fault. The VEI and/or SOC may or may not be at the highest value. Charge events normally include an initial charge and a top-off charge; in this case, the initial charge event charges the ESS to an SOC ranging from 75%-92%, and a top-off charge event is then required to complete the charge. The top-off charge event shall be conducted one time for each charging session, regardless of the SOC reading. If the ESS does not take an additional charge at the end of the initial charge event, i.e., the VEI and/or SOC is/are at the highest values(s) after the initial charge event, a top-off charge event is not necessary.

The Test or Project Engineer(s) shall remain present to begin the top-off charge within five minutes after the initial charge finishes.

4.2.3 If, upon arriving at the facility, the VEI is not at the desired value as described in Section 3.2, then the vehicle's accessory loads will be turned on to full power in order to reach the desired value. If the accessory loads do not receive energy from the traction ESS, then in order to prevent a "stranded" vehicle, the vehicle shall be driven but should not exceed a distance of two miles from the testing facility.

5 Reported Test Results

From the data collected during this testing, the following metrics are reported for the AVTE program.

5.1 Charge Duration

The total time required to charge the vehicle is reported. If applicable, the duration of the initial charge, interval between initial and top-off charge, and the duration of the top-off charge is also reported.

5.2 End-of-Charge Estimated Range

The range from the vehicle dashboard indicator at the end of charge is reported.

5.3 Charge Power

The maximum and average DC power into the ESS, P_{Charge}, is reported using the following equation:

$$(V_{ESS} \cdot I_{ESS}) = P_{Charge}$$

where V_{ESS} is ESS voltage, and I_{ESS} is ESS current.

5.4 Total Charge Energy

The total DC charge energy into the ESS, $E_{Charge\ ESS}$, is reported using the following equation:

$$\sum_{i=0}^{n}(V_{ESS_i} \cdot I_{ESS_i} \cdot \Delta t_i) = E_{Charge\ ESS}$$

where Δt_i is the i^{th} time interval.

5.5 ESS SOC

ESS SOC is reported at the following stages of the test:

- Start of charge
- End of initial charge
- End of top-off charge
- At the 30-minute charge mark

5.6 Initial and Top-Off Charge Average Power

The average power of the initial and top-off charge are reported using the following equation:

$$Avg.Power = \frac{E_{Charge\ ESS}}{Charge\ Time}$$

5.7 ESS Temperature Change

The temperature change of the ESS, ΔT, is reported using the following equation:

$$\Delta T = T_F - T_I$$

where T_F is the temperature of the ESS at the end of charge event and T_I is the ESS temperature at the beginning of charge event.

5.8 ESS Initial and Maximum Temperature

The initial ESS temperature at the beginning of a charge event as well as the maximum temperature reached during a total charge event (i.e., initial + top-off events) are reported.

5.9 Thermal Regulation Energy

The thermal regulation load is an approximate calculation of the amount of energy used by the vehicle to regulate ESS temperature, where applicable, and is reported. This is calculated by subtracting the amount of energy into the ESS from the amount of energy output by the DCFC. The calculated value also includes resistive and conversion electrical losses as well as power to run the vehicle charging system. There are three possibilities for how the onboard vehicle electronics receive power during a fast charge: 1) 12 V interface on the DCFC charger, 2) DC-to-DC converter steps high voltage down to 12 V, or 3) the system could be powered directly from the 12 V battery of the vehicle. The thermal regulation energy, E_{TR}, is calculated using the following equation:

$$E_{TR} = E_{DCFC} - E_{Charge\,ESS}$$

where E_{DCFC} is the energy output from the DCFC.

5.10 Recommended Report Plots

The following plots (at minimum) should be included in the report:

- Energy and SOC versus Elapsed Time
  - A single plot for each test temperature that includes all vehicles of a particular year and model
- Charge Power versus Elapsed Time
  - A single plot for each test temperature that includes all vehicles of a particular year and model

NOTE: The report should be set up so that all the vehicles of a particular model and year are reported on the same document.

6 Glossary

AVTE: Advanced Vehicle Testing and Evaluation

CAN: Controller area network

CECET: Center for Evaluation of Clean Energy Technology (CECET)

DCFC: Direct current fast charger

Effective Date: After a document has been reviewed and approved, the first date the procedure can be utilized in an official capacity.

Mandated Reviewer: The individual(s) responsible for the implementation of the AVTE program and of other advanced vehicle testing activities.

Energy Storage System (ESS): A component or system of components that stores energy and for which its supply of energy is rechargeable by an electric motor-generator system, an off-vehicle energy source, or both. Examples of ESSs include batteries, capacitors, and electromechanical flywheels.

Initial Conditions: Conditions that must exist prior to an event occurring.

Prerequisites: Requirements that shall be met or resolved prior to an event occurring.

Shall: This word is used to indicate an item which requires adherence without deviation. 'Shall' is used to identify the binding requirements in a statement. This is a go or no-go criterion.

Should: This word is used to identify an item which requires adherence if at all possible. 'Should' statements identify preferred conditions.

State of Charge (SOC): The ESS SOC is defined as the present capacity, (ampere-hours or watt-hours or miles), expressed as a percentage of the total available.

Test or Project Engineer: The individual(s) assigned responsibility for the conduct of any given test.

VEI: Vehicle energy indicator

7 References

SAE J1634 (Oct., 2012). “Battery Electric Vehicle Energy Consumption and Range Test Procedure”