

ETA-UTP010

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Measurement and Evaluation of Electric Vehicle Battery Charger Performance

Prepared by

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TABLE OF CONTENTS

1.0	Objective	3
2.0	Purpose	3
3.0	Documentation	3
4.0	Prerequisites	4
5.0	Charger Operation	
5.1	Parameter Identification	5
5.2	Measurement System Components	5
5.3	Measurement of AC Input Parameters	5
5.4	Measurement of DC Output Parameters	6
5.5	End of Charge Determination	6
6.0	Battery Charger Evaluation	8
7.0	Charging Efficiency	9
8.0	Glossary	10
9.0	References	12

Appendices

Appendix A - Vehicle Metrology Setup Sheet	13
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1.0 Objective

This procedure provides a consistent protocol for the evaluation of the performance of an electric vehicle's battery charger, and that charger's ability to satisfactorily recharge a vehicle's battery from any state of discharge in less than twelve hours.

Purpose

The purpose of this procedure is to provide a traceable, quantifiable methodology for the collection and evaluation of electric vehicle charger data. This activity is meant to quantify results obtained from operation of the battery charger when charging the battery from a complete discharge and when operating in the float mode. Tests of other subsystems or portions of individual subsystems are addressed by other Test Procedures. This testing and data acquisition meets the requirements specified in the UEV America Technical Requirements.

3.0 Documentation

Documentation addressed by this procedure shall be consistent, easy to understand, easy to read, and readily reproducible. This documentation shall contain enough information to "stand alone"; that is, be self-contained to the extent that all individuals qualified to review it could be reasonably expected to reach a common conclusion, without the need to review additional documentation. Review and approval of test documentation shall be in accordance with ETA-UAC004, "Review of Test Results." Storage and retention of records during and following testing activities shall be completed as described in Procedure ETA-UAC001, "Control, Close-out and Storage of Documentation."

4.0 Prerequisites

- 4.1 Personnel conducting testing under this procedure shall be familiar with the requirements of this procedure as evidenced by Certification by the Program Manager or Test Manager, any applicable SAE Test Instructions, and the Administrative Control Procedures, prior to commencing any testing activities.
- 4.2 Overall error in recording or indicating instruments shall not exceed $\pm 2\%$ of the maximum value of the variable being measured, unless otherwise excepted. Periodic calibration shall be performed and documented to ensure compliance with this requirement. [This error value does not apply to instrumentation permanently installed by the manufacturer that is required by the RFP.]
- 4.3 A list of all instrumentation used in the test shall be identified on Appendix A, and attached to the test results. It shall include the following information:
 - 4.3.1 Manufacturer
 - 4.3.2 Model Number
 - 4.3.3 Serial Number
 - 4.3.4 Last Calibration date
 - 4.3.5 Next Calibration date
- 4.4 Any deviation from the test procedure and the reason for the deviation shall be approved in advance by the Program Manager or Test Manager in accordance with ETA-UAC002, "Control of Test Conduct," and so noted on the appropriate data sheet(s).
- 4.5 Necessary recording equipment shall be installed in a manner that does not hinder vehicle operation or alter the operating characteristics of the vehicle.

5.0 Measurement of Battery Charger Parameters

The battery chargers shall be evaluated for their ability to recharge the main propulsion battery in less than twelve hours, their power factor, their effect on supply line power quality, and the Total Harmonic Distortion (THD) introduced by the charger. Several of these evaluations are completed concurrently, and are described in the following sections.

5.1 Measurements of the following parameters shall be performed to complete the charger evaluations.

5.1.1 AC input voltage

5.1.2 AC input current

5.1.3 Battery voltage

5.1.4 DC current.

5.2 The measuring system shall have three main components:

5.2.1 Sensors, including potential transformers and AC and DC current transformers.

5.2.2 Signal conditioners, including isolation amplifier and attenuator.

5.2.3 Data acquisition system (LabVIEW)

5.3 AC Input Parameters

The input AC parameters shall be measured using a potential transformer and current transformer. The potential transformer (PT) shall have a ratio of 4:1 to reduce the line-to-neutral voltage. The voltage signal shall be further reduced using attenuation through an isolation amplifier. The output of the amplifier shall then be fed to the acquisition system. The AC line current shall be measured using a clamp-on current transformer (CT), with a ratio of 1000:1 and a frequency response of DC to 400Hz. On the secondary side of the CT, a resistor with a value of 10 Ω , a 100 Ω , or 1000 Ω shall be connected, in order to obtain a measurable voltage drop. This voltage will be proportional to the line current and will be fed to the data acquisition system.

5.4 DC Output Parameters

The DC voltage of the battery shall be measured using the proper attenuation in the isolation amplifier. The DC current shall be measured using an AC/DC CT. The CT shall have a $\pm 2V$ analog output which will be directly fed to the acquisition system, with a frequency response of 0 to 2 kHz.

The signals are first passed through a signal conditioning and amplifier unit which provides the necessary signal levels for compatibility with the A/D converter. The program shall sample at a frequency of at least 21.6 kHz, acquiring at least 720 points per channel, and covering at least two cycles of the 60 Hz waveform. This sampling frequency will ensure adequate resolution for the power quality measurements.

- 5.5 Using the collected samples, the required parameters shall be calculated every 30 seconds and stored in a data file. The following parameters shall be calculated:
- 5.5.1 V_{rms} of the AC input voltage
 - 5.5.2 I_{rms} of the AC input voltage
 - 5.5.3 THD of the AC input voltage
 - 5.5.4 THD of the AC input current
 - 5.5.5 AC active power
 - 5.5.6 Harmonic power
 - 5.5.7 Total apparent power
 - 5.5.8 Harmonic apparent power
 - 5.5.9 True power factor
 - 5.5.10 Displacement power factor
 - 5.5.11 Battery voltage
 - 5.5.12 DC value of the charging current
 - 5.5.13 Ripple factor of the charging current
 - 5.5.14 Ampere-hours
 - 5.5.15 Watt-hours
 - 5.5.16 Charger efficiency (DC power out / AC power in)

These data shall be saved in columns along with the time stamp, to be used to plot the required waveforms as a function of time. Power quality calculations use the fundamental components of the voltage and current. These fundamental components shall be calculated using the Fourier series expansion. Through operator control, the acquired data shall also be saved in a separate file to allow plotting of the input voltage and current waveforms. This function should be performed at various times in the charging cycle, including the beginning, mid-point and end.

- 5.6 Determination of the End of Charge Point for Vehicle Batteries.

The vehicle manufacturer shall have provided the data indicating the point at which the main propulsion batteries are fully charged in their proposal. This data can also be obtained from the information collected during the completion of procedures ETA-UAC006, "Vehicle Verification," and ETA-UTP011, "Receipt Inspection," (which used the manufacturer's Proposal as a source document).

It is conceivable, however, that a vehicle manufacturer has not or cannot provide this data. For example, this could occur when the car is a prototype as defined by the UEV America RFP. In this situation, all of the following of criteria shall be satisfied prior to declaring the battery fully charged (100% SOC).

- 5.6.1 The Battery Pack Charging Voltage has stopped increasing and has been stable to within one volt for a minimum of one (1) hour, determined by a minimum of seven (7) consecutive readings taken a minimum of 10 minutes apart, AND
- 5.6.2 The Battery Pack Charging Current has stopped decreasing and has been stable to within one ampere for a minimum of one (1) hour, determined by a minimum of seven (7) consecutive readings taken a minimum of 10 minutes apart, AND
- 5.6.3 The charger indicator shows that the charge is complete. This may be a meter reading, a light, a beeper, or the charger turning off, as specified by the manufacturer.

6.0 Battery Charger Evaluation

This section provides detail on conducting the evaluation of the charger capability. Perform the following:

- 6.1. Discharge the main propulsion battery to the minimum SOC allowed by the manufacturer by driving vehicle per UTP004, Section 5.1 (Constant Speed Range Test). This point should be obtained from the manufacturer's Proposal.)
- 6.2. Within two hours of completing Step 6.1, place the vehicle on charge in accordance with procedure ETA-UTP008, "Battery Charge." Record the time the charger supply disconnect is closed per ETA-UTP008.
- 6.3. Monitor the AC and DC parameters during the entire charge period.
- 6.4. Determine the end of charge per Section 5.5 of this procedure and note the time.
- 6.5. Note the time the vehicle indication of full charge (if this time is different from the method specified in Section 5.5) shows the batteries fully charged.
- 6.6. Charge for 13 hours or until section 6.4 and 6.3 are complete
- 6.7. Verify the time to full charge is less than 12 hours by reviewing the stored data.
- 6.8. Verify the maximum current was less than 40 Amps at all times.
- 6.9. Plot the parameters listed in Section 5.5.1 of this procedure.

7.0 Charging Efficiency

This section will determine the efficiency of the charger, when measured over a specified set of activities. For this effort, the energy required by the charger to return and maintain the propulsion battery in a full state of charge will be determined. The vehicles range through the Endurance Course Test (ETA-UTP007) will provide the basis for discharge. Conduct the testing as described below.

- 7.1 Immediately prior to commencing the first phase of ETA-UTP007, read and record (per ETA-UTP008) the supply side kWh meter value for the vehicle being tested.
- 7.2 Complete the first days testing per ETA-UTP007.
- 7.3 Immediately prior to commencing the second phase of ETA-UTP007, read and record (per ETA-UTP008) the supply side kWh meter value for the vehicle being tested.
- 7.4 Complete the second days testing per ETA-UTP007.
- 7.5 No later than 8 AM on the morning following the completion of the second phase of ETA-UTP007, read and record the (per ETA-UTP008) the supply side kWh meter value for the vehicle tested.
- 7.6 From the test logs, determine the total miles driven during the completion of ETA-UTP007.

NOTE

The values calculated in Steps 7.7 and 7.8 are recorded only on the Data Sheet.

- 7.7 Using this mileage, and the total kWh-AC used by the charger during the two day period, calculate the miles per kWh-AC as follows:

$$\text{Miles per kWh-AC} = (\text{Total Energy Returned} / \text{Total Miles Driven})$$

- 7.8 Using the Miles per kWh-AC calculated in Step 7.7, and a given rate of 10¢ per kWh-AC (an average daily rate sans demand charges), calculate the cost per mile to charge as follows:

$$\text{Cost per Mile} = (10¢ \text{ per kWh-AC} / \text{Miles per kWh-AC})$$

7.0 Glossary

- 8.1 Effective Date - The date, after which the procedure has been reviewed and approved, that the procedure can be utilized in the field for official testing.
- 8.2 Orthogonally - As used here; consisting of the x , y and z axes (three dimensional).
- 8.3 Program Manager - As used in this procedure, the individual within Electric Transportation Applications responsible for oversight of the UEV America Performance Test Program. [Subcontract organizations may have similarly titled individuals, but they are not addressed by this procedure.]
- 8.4 Shall - Items which require adherence without deviation. Shall statements identify binding requirements. A go, no-go criterion.
- 8.5 Should - Items which require adherence if at all possible. Should statements identify preferred conditions.
- 8.6 Snapshot - A term given to the time frame that normally accompanies a single event or a number of concurrent events. Usually indicates a repetitive series of events is occurring or is meant to occur.
- 8.7 State of Charge (SOC) - For this testing, the SOC of a battery is defined as the expected residual battery capacity, expressed in amperes-hours or watt-hours or miles, as a percentage of the total available. The 100% SOC basis (available ampere-hours, kilowatt hours or miles) is determined by the actual discharge capability of the main propulsion battery when discharged to the requirements of the 35 mph Constant Speed Range Test portion of procedure ETA-UTP004.
- 8.8 Test Director - The individual within Electric Transportation Applications responsible for all testing activities associated with the UEV America Performance Test Program.
- 8.9 Test Director's Log - A daily diary kept by the Test Director, Program Manager, Test Manager or Test Engineer to document major activities and decisions that occur during the conduct of a Performance Test Evaluation Program. This log is normally a running commentary, utilizing timed and dated entries to document the days activities. This log is edited to develop the Daily Test Log published with the final report for each vehicle.
- 8.10 Test Engineer - The individual(s) assigned responsibility for the conduct of any given test. [Each contractor/subcontractor should have at least one individual filling this position. If so, they shall be responsible for adhering to the requirements of this procedure.]

8.0 Glossary (continued)

- 8.11 Test Manager - The individual within Electric Transportation Applications responsible for the implementation of the test program for any given vehicle(s) being evaluated to the requirements of the UEV America Performance Test Program. [Subcontract organizations may have similarly titled individuals, but they are not addressed by this procedure.]
- 8.12 Time Stamp - The arbitrary time zero (t_0) denoting the beginning of an event.

9.0 References

- 9.1 UEV America Technical Requirements
- 9.2 IEEE-450 1987, “Recommended Practices for Stationary Lead Acid Storage Batteries”
- 9.3 ETA-UAC001, Revision 0 - “Control, Close-out and Storage of Documentation”
- 9.4 ETA-UAC002, Revision 0 - “Control of Test Conduct”
- 9.5 ETA-UAC004, Revision 0 - “Review of Test Results”
- 9.6 ETA-UAC005, Revision 0 - “Training and Certification Requirements for Personnel Utilizing ETA Procedures”
- 9.7 ETA-UAC006, Revision 0 - “Vehicle Verification”
- 9.8 ETA-UAC007, Revision 0 - “Control of Measuring and Test Equipment”
- 9.9 ETA-UTP003, Revision 0 - “Electric Vehicle Energy Consumption and Range Test”
- 9.10 ETA-UTP004, Revision 0 - “Constant Speed Range Test”
- 9.11 ETA-UTP011, Revision 0 - “Receipt Inspection Procedure”

APPENDIX-A
Vehicle Metrology Setup Sheet
(Page 1 of 1)

VIN Number: _____

Instrument/Device:	Calibration Due Date:	Initials / Date:
Comments (initials/date):		
<p>Completed By: _____ (Printed Name) (Signature) (Date)</p> <p>Reviewed By (QA): _____ (Printed Name) (Signature) (Date)</p> <p>Approved By: _____ (Printed Name) (Signature) (Date)</p>		