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Plug-in Electrical Vehicle Charge Rate Reporting and Test Procedures

RATIONALE

For the purposes of comparing charging capabilities of electric vehicles (EVs) and electric vehicle supply equipment (EVSEs), a unified methodology of reporting the charging rate is needed in the field. This document will provide common test procedures to consistently measure capabilities of vehicles and EVSEs for the consumer and media to use for clear comparisons. This document describes testing and reporting schema for direct current (DC) charging systems as applied to light duty passenger vehicles directly connected charging systems. Extensions may be added (as needed) for alternating current (AC) charge and/or wireless power transfer (WPT) systems. This document is relevant to passenger vehicles.

FOREWORD

In conventional internal combustion engine and hybrid vehicles, the time required to refill liquid- or gas-fueled vehicles is not significant and is generally not considered to be a differentiator when the vehicle is marketed, nor is it used by the consumer while comparing the capabilities of different vehicles. The longer time required for EV recharging represents a paradigm shift in customer usage which is known, but not well understood, by the general public and often results in confusion. This results in a significant difference in the way EVs are marketed and thus "charging time" remains a key concern of potential EV buyers.

Full AC charge time is currently reported on the vehicle fuel economy label. It identifies the time required for the vehicle to charge from completely empty to completely full using a best-case scenario with an AC charger. This was developed during a period when EV ranges were short and most charges were for nearly the full range. With the increase in EV ranges, the full charge time metric has become less useful as a comparison tool and generally less relevant to daily usage, though still reported and use for comparisons. This continued use results in confusion as:

a. Full charge time is proportional to full range. Comparing different times for vehicles with different ranges causes the longer-range vehicles to appear to be slower at charging than shorter range vehicles. In reality, this is an artifact of larger batteries requiring more energy to be full, and results in a confusion point to consumers.

b. Vehicle charging is infrequently a zero to full event. In most cases, it is the replacing of driven miles while the driver is engaged in another activity such as sleeping or working. The time it takes to replace the miles driven is not a function of "vehicle charge time," but rather time it requires to replace the number of miles used. Therefore, using a zero to full metric is not giving the consumer a basis on which to judge the fitness of the vehicle for their daily life.

Large-capacity batteries and high-power EVSEs available in the marketplace have resulted in "charge time," the time from empty to full battery, being less important than "charge rate." Furthermore, an AC charge time is not useful for predicting the duration of DC charging in which the operator is waiting for the charge to end, such as when on a longer distance trip or other times when the charging is not done in parallel with other life activities (working, sleeping, etc.).

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Many corporate marketing organizations have taken note of the downside of advertising long charge times and have chosen to use DC charging times and/or rates. Historically, these efforts have been uncoordinated between manufacturers and have led to a marketplace where many different reporting paradigms are prevalent. This makes it difficult for a consumer to directly compare capabilities during the purchasing process and provides a source of confusion regarding how the vehicle will or will not fit their usage. Furthermore, lack of a common metric and test procedure leaves room for exaggeration and reporting of values that would not be seen in real-world use.

This document is intended to address that aspect with a straightforward test designed to compare different vehicles in real-world—albeit very good—conditions, which will simultaneously allow the capabilities of the vehicle to be better understood, while giving the customer a comparable metric to use when looking at different vehicles. By doing so, it will encourage better vehicle designs and infrastructure that minimizes charging rate and not on targeting the test.

This test procedure is intended to be used by all charge coupler types currently in the market.

Currently, 16 CFR 309 exists to describe the capabilities of the EVSE power measurement. This document will not attempt to rewrite that work, but does build upon it to include a duration that the EVSE is expected to deliver the rated power. This duration is coordinated with the vehicle test metric.

Future versions of this document will address AC and wireless charging rates with the intent of establishing a common rate metric that will provide a good comparison between DC, AC, and WPT. Variables that affect the rate of charge, such as temperatures, EV-EVSE pairing, starting SOC, actual drive energy, EVSE sharing, and other such real-time aspects may be addressed in future versions if the evolving marketplace warrants it. Future versions of this document may be used for recommendations for calculating and reporting to normalize what the consumer experiences, but will not impose any standards as this vehicle-driver interaction is ripe for innovation and could become be a brand-defining feature of an OEM.

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1. SCOPE

This document facilitates clear and consistent comparisons of realistic charging capabilities of passenger vehicles via commercially available DC EVSE. Common test procedures and metrics are established for both vehicles and EVSEs operating without limitations in nominal conditions. This document does not attempt to address performance variations of EV-EVSE interactions outside of nominal conditions such as extreme temperatures, variable SOCs, and so on.

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 +1 724-776-4970 (outside USA), www.sae.org.

SAE J1634 Battery Electric Vehicle Energy Consumption and Range Test Procedure

SAE J2894/2 Power Quality Test Procedures for Plug-in Electric Vehicle Chargers

2.1.2 Code of Federal Regulations (CFR) Publications

Available from the United States Government Printing Office, 732 North Capitol Street, NW, Washington, DC 20401, Tel: 202-512-1800, www.gpo.gov.

16 CFR Part 309 Labeling Requirements for Alternative Fuels and Alternative Fueled Vehicles

3. DEFINITIONS

3.1 ALTERNATING CURRENT (AC) LEVEL 2 CHARGING

A method that uses dedicated AC EV/PHEV supply equipment in either private or public locations. The vehicle shall be fitted with an on-board charger capable of accepting energy from single phase AC electric vehicle supply equipment.

3.2 AMBIENT TEMPERATURE

The air temperature outside the vehicle. Not to be confused with the temperature immediately surrounding a component (e.g., underhood or undercar temperature) or a range of temperatures (e.g., 20 to 30 °C—aka, “room temperature”).

3.3 BATTERY (RESS)

A device consisting of one or more electrochemical cells electrically connected in a series and/or parallel arrangement. Often used as shorthand for traction battery, a battery that provides power to propel a vehicle. Traction batteries are typically electrically rechargeable, with charge power supplied from the electrical grid through a charger, from energy captured from regenerative braking, and/or from power generated by a fuel-powered engine.

3.4 BATTERY AMPERE-HOUR CAPACITY

The capacity of a battery, in ampere-hours (A•h), obtained from a battery discharged at the manufacturer’s recommended discharge rate such that a specified cut-off terminal voltage is reached.

3.5 BATTERY ELECTRIC VEHICLE (BEV)

A vehicle that receives its power solely from batteries, unlike a hybrid vehicle that may receive a portion of its power from a separately-fueled power source, such as an internal combustion engine.

3.6 CHARGE RATE

The rate at which usable energy is returned to the vehicle battery from an offboard source expressed in miles per minute.

3.7 CHARGER

An electrical device that converts alternating current energy to regulated direct current for replenishing the energy of a rechargeable energy storage device (i.e., battery) and may also provide energy for operating other vehicle electrical systems. This may be located on-board (aka, on-board charger [OBC]) or off-board (aka, DC charger).

3.8 CONNECTOR (CHARGE PLUG)

A conductive device that by insertion into a vehicle inlet establishes an electrical connection to the electric vehicle for the purpose of transferring energy and exchanging information. This is part of the coupler.

3.9 COUPLER

A mating vehicle inlet and connector set.

3.10 DIRECT CURRENT (DC) CHARGING

A method that uses dedicated DC EV/PHEV supply equipment to provide energy from an appropriate off-board charger to the EV/PHEV in either private or public locations.

3.11 DIRECT CURRENT (DC) DISCHARGE ENERGY CONSUMPTION

Variable: ECDC. The energy withdrawn from the battery pack for operating the vehicle on a per mile basis (watt-hour per mile) as measured by the test procedure defined in SAE J1634.

3.12 ELECTRIC VEHICLE SUPPLY EQUIPMENT (EVSE)

The conductors, including the ungrounded, grounded, and equipment grounding conductors and the electric vehicle connectors, attachment plugs, and all other fittings, devices, power outlets, or apparatuses installed specifically for the purpose of delivering energy from the premises wiring to the electric vehicle.

3.13 FULL CHARGE (FC)

The battery state associated with maximum off-board stored energy capacity established by using the manufacturer's recommended charging procedure and appropriate equipment. At full charge, the vehicle should indicate full charge by an easily read indicator somewhere in or on the vehicle.

3.14 HUMAN MACHINE INTERFACE (HMI)

The interface or controls that an operator may adjust, and the human readable feedback given to the operator on a piece of equipment.

3.15 JOULE LOSSES (JOULE HEATING)

The energy lost during charging or discharging the battery cells. Notable in the context of this document, during charging, the joule losses are the difference between the electrical energy entering the battery cells (integration of voltage * current) and the usable battery electrochemical energy stored in the cells.

3.16 NET BATTERY CURRENT

The sum of all currents simultaneously entering or leaving the battery cells. This may be a single measurement point or multiple measurement points depending on the electrical distribution inside the battery pack.

3.17 PREDICTED RANGE

The electric driving range remaining before the vehicle comes to a stop as predicted by a vehicle display or feedback. For the purposes of this document, the unit of "miles" is used unless otherwise noted.

3.18 PLUG IN ELECTRIC VEHICLE (PEV)

Either a PHEV or BEV or other vehicle that operates in whole or in part on electric energy and can be recharged from a grid connection

3.19 PLUG IN HYBRID ELECTRIC VEHICLE (PHEV)

A hybrid vehicle with the ability to store and use off-board electrical energy in a rechargeable energy storage device.

3.20 RECHARGED USABLE BATTERY ENERGY (rUBE)

The energy added to the battery during charging which is available for discharging at a later time. This value is equivalent to the energy added to the battery pack minus the joule losses.

3.21 SOAK

The period of a preconditioning stage that is focused on allowing the test setup to come naturally to a defined temperature. This is often accomplished through the use of a climatically controlled space.

In the context of this document, the term is used to distinguish the difference preparing the temperature of the vehicle from preparing other conditions. See Appendix C for the background of this distinction.

3.22 STATE-OF-CHARGE (SOC)

The percentage of useable energy remaining in the battery pack relative to the battery pack's full charge useable energy.

3.23 VEHICLE INLET (CHARGE INLET)

The device on the electric vehicle into which the connector is inserted for the purpose of transferring energy and exchanging information. This is part of the coupler.

3.24 VEHICLE PARKED STATE

The vehicle has been put in a state where it will may stationary for an indefinite period of time, even in loss of on-board power (e.g., dead or removed battery), using only mechanical roll-away prevention measures on-board (park pawl, parking brake, other), and the key or other device for authorization the starting system of the vehicle has been removed such that the starting system may not be operated. The end of this state is indicated when the vehicle receives a signal authorizing entry or other vehicle operation beyond information query. Guidance from the manufacturer, if supplied, should be followed to ensure a "parked" vehicle.

Note that this is the condition formerly regarded as gear selector in "P" and key removed. Changes in both gear selector and key technology, as well as after-run operations, has made a more formal definition necessary.

3.25 WIRELESS POWER TRANSFER (WPT)

Wireless charging of a plug-in vehicle utilizing an off-board component and an on-board component to transfer grid energy to and/or from the vehicle through an air gap.

4. ACRONYMS

Table 1 lists the acronyms used in this document in the order of first appearance.

Table 1 - Acronyms used in this document

Acronym	Term
AC	Alternating current
A/C	Air conditioning
BEV	Battery electric vehicles
DC	Direct current
EOT	End-of-test
EVSE	Electric vehicle supply equipment
FC	Full charge
HMI	Human machine interface
NIST	National Institute of Standards and Technology
SOC	State-of-charge
UBE	Useable battery energy
WPT	Wireless power transfer
PHEV	Plug-in hybrid electric vehicle
PEV	Plug-in vehicle
RESS	Rechargeable energy storage system

5. DETERMINATION OF EV CHARGING RATE

5.1 Test Conditions and Instrumentation

The following conditions shall apply to all tests defined in this document unless otherwise stated in specific test procedures.

5.1.1 Condition of Vehicle

All accessories shall be turned off except those required by the test procedure.

5.1.2 Condition of Battery

The battery and battery management controls shall be production versions.

No requirements on the calendar age of the battery. It is recommended that the battery have less than 3000 miles of use.

All batteries shall be cycled in accordance with the vehicle manufacturer's recommendations, if any, before starting testing. Battery ampere-hour capacity shall be verified to be within acceptable limits using the manufacturer's recommended procedure as provided for SAE J1634 and should be verified at least once following the completion of vehicle testing.

5.1.3 Environmental Conditions

Ambient temperatures during vehicle and battery ambient soak (if any), test, and recharge period shall all be within the range of 20 to 30 °C (68 to 86 °F).

5.2 Test Instrumentation

This section provides a list of instruments that are required to perform the tests specified in this document.

5.2.1 General Instrumentation

All measurements shall be NIST-traceable (National Institute of Standards and Technology). The following instruments are either additionally required or recommended for as-needed usage:

Measurements in the high voltage system

a. A DC wideband voltage, ampere-hour, and watt-hour meter (e.g., a power analyzer with integration functions for energy calculations). Sensors such as current, voltage, and/or temperature are connected to this device. Voltage of the battery pack or charge coupler are measured directly with this meter. Net battery current is summed from all applicable sensors and ampere-hour calculations are performed. The device shall have an environmental rating, including ambient temperature, that meets the rating of the test environment. Devices which record measurements or perform calculations using the assumption that the electrical frequency is a fixed 50 Hz or 60 Hz are not sufficient.

b. Total accuracy of voltage measurements (sensor plus data collection system) shall be 1% of the reading or 0.3% of full scale required for this test, whichever is larger.

c. Total accuracy of current measurements (sensor plus data collection system) shall be 1% of the reading or 0.3% of full scale required for this test, whichever is larger. Note: if multiple current sensors are used to sum individual paths, the total error of the calculation when summed shall be the same or better as the given above.

d. DC wideband current measurements. It shall be installed in such a way as to measure all current leaving and entering the battery cells regardless of the number of connections on the pack. If a single sensor cannot measure the total flow, multiple sensors may be used and summed provided that the total error of the summation is within the required tolerances and the sampling rate of all sensors is the same.

e. As the current and voltage sensors are used in long duration integration calculations, possible offset errors of sensors should be checked and corrected for prior to the test, and confirmed to have remained within tolerance after the conclusion of the test.

f. Wideband instruments (bandwidth of at least ten times that of the maximum fundamental frequency of interest) are required where pulsed power electronics are implemented. Any watt-hour meter using an integration technique shall have a maximum integration period of 0.05 second so that short bursts of regeneration energy and current can be accommodated without causing integration errors.

As an alternative to paragraph (a), the manufacturer may use the on-board voltage measurement data. The accuracy of these data shall be demonstrated to have the required accuracy when compared to NIST-traceable instruments that would be otherwise used. As an alternative to paragraphs (a), (b), and (f), the manufacturer may use on-board RESS current measurement data. The integrated value of current (A•h) should be performed by the vehicle at 20 Hz or greater prior to communicating through CAN.

Temperature measurements: ±2.5 °C.

Delta time should be within 5 seconds of accuracy. It is recommended to use the time index of a data logging instrument or power analyzer.

5.2.2 Data to Be Documented for All Tests

The following data shall be documented for all tests. If the parameter does not apply to the test as performed (e.g., using on-board data source versus instrumented battery voltage sensor), the absence of the sensor and rationale should be documented.

Table 2 - Data to be recorded

Item	Parameter/Measurement	Description	Units
1	Current sensor(s) used	Type, serial number, calibration data	
2	Voltage sensor(s) used	Type, serial number, calibration data	
3	A•h or W•h meter (power analyzer) used	Type, serial number, calibration data, settings which are modified from factory settings	
4	EVSE rated/nameplate voltage, power and current (for vehicle test)		kW/A/V
5	EV published max charge power and current (for EVSE test)		kW/A/V

5.2.3 Data to Be Recorded During Tests

Table 3 lists the data and parameters that must be recorded in order to perform vehicle and EVSE tests listed in this document, unless explicitly stated. The determination of certain items in this table may inherently require the measurement of intermediate quantities not explicitly listed (e.g., current, voltage).

Table 3 - Required parameters to be recorded

Item	Parameter/Measurement	Description	Units
1	DC voltage	Voltage at either the battery pack or charge coupler, measured or reported by the vehicle at 10 Hz or faster rate (see 5.2.1)	V
2	Net DC current at battery	The sum of all currents entering and exiting the battery cells, measured or reported by the vehicle at 10 Hz or faster rate (see 5.2.1)	A
3	DC current at vehicle inlet	Recorded at 20 Hz or faster rate (see 5.2.1)	A
4	Ambient test temperature	Temperature of the air in the room or area around the vehicle, shaded from direct sun and wind, recorded at a minimum 1 Hz	°C (°F)
5	Vehicle predicted remaining range	Vehicle displayed or reported range remaining until empty	Miles or kilometers
6	EVSE errors (to monitor for EVSE limitations)	Any reported errors detected by the EVSE	
7	EV errors (to monitor for EV limitations)	Any reported errors detected by the EV	
8	Time, end of vehicle soak period	Total time vehicle is soaking	Minutes
9	Time, end of charging period	Total time vehicle is charging	Minutes

5.3 Test Procedure

5.3.1 Pre-Calculations and Variables

It is assumed that the vehicle has been driven on the SAE J1634 test procedure used on cycles required by 40 CFR 600 and the following values from that test are available. The values shall be drawn from the same test data which are used to report range and energy economy.

a. $ECDC_{total}$ = DC discharge energy consumption calculated using DC discharge energy for the complete cycle required by 40 CFR 600 (using Edc_{total} and total cycle distance).

b. Required measurements during vehicle certification test procedure to measure UBE.

The change of electric energy (ΔE_{RESS}) of all RESSs shall be recorded for each RESS SOC point during the applicable SAE J1634 drive cycle as $\Delta E_{RESS,i}$. $\Delta E_{RESS,i}$ is the UBE (in kilowatt-hours) associated to SOC point i (percent), defined as the energy change during discharge between the RESS SOC change from i to i-1 and the RESS SOC change from i-1 to i-2.

Example: The RESS SOC point is i = 80%. The cumulated consumed energy $\sum_{ECDC}$ at the point in time the RESS SOC indication changes from 80 to 79% is 20 kW•h. The cumulated consumed energy $\sum_{ECDC}$ at the point in time the RESS SOC changes from 79 to 78% is 21 kW•h. As a result, the associated UBE content of the 80th RESS SOC point $\Delta E_{RESS,80}$ is the 21 kW•h - 20 kW•h = 1 kW•h.

Test duration for metric reporting:

T_{test} = 10 minutes

Note: During the initial TIR of this document, it is requested that two additional T_{test} durations are used in the post calculations: T_{test_short} = 5 minutes and T_{test_long} = 20 minutes (with a subsequent increase of testing time to T_{test_long}). This data will be used to reevaluate the duration of the metric in future versions of this document.

c. Vehicle Prep:

1. Charge or discharge the vehicle to a range that is sufficient to allow for the required indicated range for performing the test (5.3.1.2), after performing any precondition (5.3.1.1).

   Engineering judgement is required for this preparation.

2. A soak period is optional. The vehicle, including battery, should not at be extreme temperatures. If OEM recommendations are not available, the temperature range as described in environmental conditions above is recommended.

d. The vehicle manufacturer may recommend an EVSE. If not specified by the manufacturer, the EVSE shall be capable of delivering full rated current and power of the vehicle at the voltage required by the vehicle without limitations from the EVSE.

5.3.1.1 Precondition Vehicle

The vehicle should be preconditioned per the OEMs recommendation with the following guidelines.

The preconditioning should be 30 minutes or less.

The precondition may require a special mode (e.g., “dyno mode”) to enable advanced features used to prep the battery for the quickest charge. In an ideal situation, the operator can activate such precondition manually through an HMI interface. An example of such a feature provided as illustration, but not meant to limit the possibilities: a navigation based integration that uses predicted time-of-arrival and arrival-SOC to heat, cool, or otherwise prepare the battery to charge rapidly upon arrival at the destination charger. It is recommended that the conditions required to achieve the fastest charging is clearly described in the vehicle manual and publicly available knowledge.

The precondition should not require a special soak room nor chassis dyno. The precondition should be possible by driving in an ambient temperature range of -10 to 35 °C. If no recommendation by the OEM, the precondition shall be operation of the vehicle for 30 minutes over a minimum of 10 miles.

At the end of the precondition, the estimated range on the vehicle should be between 15 miles and 25 miles remaining or per the OEM recommendation.

At the end of the precondition, the vehicle shall be plugged in and the test started with a delay not longer than 30 minutes.

5.3.1.2 Test

1. Test environment: The vehicle shall stand in an environment, ideally indoors, with the following attributes.

   a. Ambient temperature as described in 5.1.3.

   b. No sun load.

   c. Wind less than 10 km/h.

   d. Minimum 1 m clearance around vehicle radiators and condensers (keep in mind that these heat exchangers may not always be in the front).

2. Vehicle state:

   a. Parked, parking brake enabled.

   b. Doors closed, unoccupied.

   c. Key removed from vehicle, but vehicle in a state that allows charging.

   d. Vehicle loads (chiller, pumps, lights, etc.) controlled by the vehicle.

e. Vehicle to be set in a mode to allow the fastest charging without regard to any other driver selectable options.

f. Vehicle controls set to allow a full, 100% SOC battery charge.

3. Perform charging test:

a. Start data capture.

b. Insert DC charge connector.

c. Wait until either:

i. The vehicle commands charging to stop (e.g., full battery).

ii. Recommended to use a duration of >120% of t_{test} (or t_{test_long}) to ensure sufficient data available for post processing of all test durations. The results of different reported values will be calculated in post processing.

d. Remove connector.

e. Stop data collection.

f. Post process.

5.3.1.3 Post Process: Calculation of Charge Rate

a. Determine recharged usable battery energy (rUBE):

1. Calculation of recharged usable battery energy (rUBE) within the designated period of time.

Using the data from the measurements during certification tests and charging cycles, the recharged usable energy equivalent rUBE within the period of n minutes shall be calculated as the sum of all fully covered SOC points, taking the last uncompleted SOC point k+1 proportionally into account:

$$\mathrm{rUBE}\ (t_{test}\ \mathrm{min}) = \sum_{i=j+1}^{k} \Delta E_{RESS,i} + \frac{t_{test} - \Delta t_k}{\Delta t_{k+1} - \Delta t_k} * \Delta E_{RESS,k+1}$$

where:

rUBE = recharged usable battery energy

t_{test} = test duration in minutes

i = a single SOC increment

j = initial SOC at start of measurement

j+1 = the reported SOC at which to start the result calculations for energy and duration

k = final full SOC increment achieved before the end of the test duration

ΔE_{RESS} = change in energy in the RESS during that SOC increment as per DC energy consumption measurements (ECDC) during the applicable driving portion of SAE J1634 energy consumption test

$\Delta E_{RESS,k+1}$ = the energy added during the SOC increment that spans before and after the end of the test duration

Δt_k = the test duration at the beginning of the final SOC increment

Δt_{k+1} = the test duration at the end of the final SOC increment

Example: The designated period of time t_{test} is 5 minutes. At 20 miles of indicated remaining range, a SOC of 9% is indicated in the vehicle instrumentation. Thus, the initial SOC j = 10%. After beginning to charge, time measurement starts at the SOC change from 9% to j = 10%. After 4.7 minutes, SOC k = 23% is achieved; SOC k+1 = 24% is reached after 5.2 minutes. As a result, the recharged usable energy rUBE is calculated as the sum of the energy content equivalents within the 11th to 23rd SOC points with proportional consideration of (5 minutes - 4.7 minutes)/(5.2 minutes - 4.7 minutes) = 0.3/0.5 = 60% of SOC point k+1 = 24% via the formula:

$$\mathrm{rUBE}\ (5\ \mathrm{min}) = \sum_{i=11}^{23} \Delta E_{RESS,i} + 60\% * \Delta E_{RESS,24}$$

2. Calculate the distance added to the vehicle battery.

$$d_{added} = \mathrm{rUBE} / \mathrm{ECDC}\ \text{(in miles)}$$

Round down to the nearest mile (“floor” function).

3. Final value is d_{added} per t_{test} in miles/t_{test}.

   i. Do not reduce to miles/minute; keep the t_{test} value in the rating.

   ii. Example: t_{test} = 10 minutes and d_{added} was measured as 57 miles, the rating is 57 miles/10 minutes.

   iii. Note: If the charge ends due to a full battery (100%) prior to reaching t_{test_long}, record the full label range as the result.

NOTE: Requirements for re-calculating the values from this test:

If changes in the vehicle, including over-the-air updates of battery management calibrations, would result in decreasing the integrated energy provided to the vehicle to less than 98% of the original measurement, it is necessary to reevaluate using this test procedure

If changes are made to the vehicle which otherwise require a retesting of SAE J1634 which results in the ECDC value increasing by more than 2%, it is necessary to reevaluate using this test procedure.

Not all changes require the rerun of the physical DC charge metric test. Recalculation using existing test data may be used, first generating the new ECDC from SAE J1634 then recalculating the rUBE from existing data using the above calculations, if the changes in the vehicle would not vary the DC charging energy during the test by more than a 2% decrease.

6. DETERMINATION OF EVSE CHARGING RATE

6.1 EVSE Test

The EVSE reporting capability is defined in 16 CFR 309 with regard to consumer protection. However, the measurement can be an instantaneous measurement and may not consider changes across the duration of the power delivery. The EVSE shall be tested for the rated capability for the duration t_{test} using the following procedure.

6.2 Instrumentation

Voltage and current sensors that meet the requirements in Section 5 at the charge coupler.

6.3 EVSE Prep

The EVSE shall be installed per manufacturer’s requirements. The electrical grid interface shall meet the manufacturer’s specifications. Any required cooling or ventilation shall be met.

The EVSE shall have been allowed to soak unused for at least 1 hour prior to the test. During this soak, the grid power shall remain on and any normal cooling or ventilation is allowed to operate. The coupler shall remain disconnected from the vehicle or vehicle surrogate during this period.

6.3.1 Vehicle or Vehicle Substitute

A vehicle or vehicle substitute (regenerative load bank with vehicle charger communication emulation) shall be chosen to accept the same or higher power at a given voltage as the EVSE is expected to test against. If a vehicle substitute is used, the charging profile is not required to follow a battery model whereby the voltage is dependent upon the current and battery conditions including SOC; instead, in the interest of shorter and more reproduceable tests, the vehicle simulator may be programmed to accept the target current, power, and voltage at a constant rate. The goal of this test is to confirm that the rate can be sustained for the given duration.

The vehicle or vehicle substitute shall be soaked in a low power state until it is expected to avoid having internal limits which would invalidate this test.

6.4 Test Procedure

Plug EVSE into vehicle or vehicle substitute.

Run test for a minimum of 120% of T_{test} (as used in the vehicle testing). A longer time period may be appropriate when using a vehicle to allow for sufficient time for the power to increase to full potential. The goal is to find a duration of time, T_{test}, where the EVSE can demonstrate constant power.

P_{EVSE_Target} = Power reported as per 16 CFR 309 requirements.

If the EVSE supplies power without reducing to less than 0.98 * P_{EVSE_Target}, then SAE J2953-4 EVSE power is equal to that reported per 16 CFR 309.

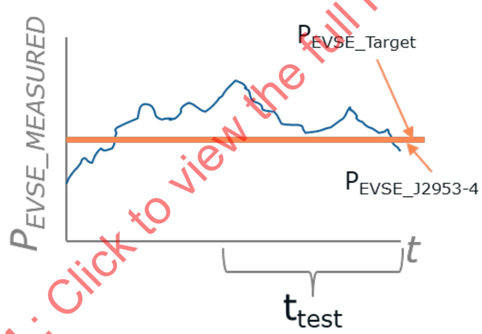


Figure 1 Example identification of SAE J2953-4 EVSE Power

If the EVSE reduces power, then the SAE J2953-4 reported power is the minimum power that is held for T_{test}.

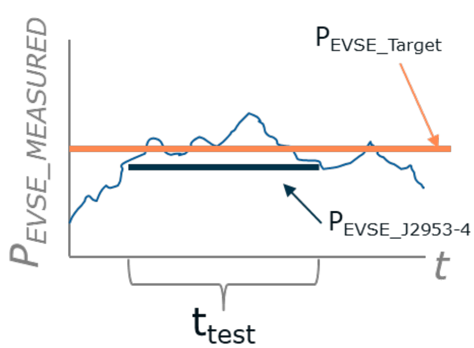


Figure 2 Example identification of SAE J2953-4 EVSE Power during varying charge power

If the EVSE supplies a power level continuously higher than P_{EVSE_Target} for more than T_{test} duration, the SAE J2953-4 rated power may alternatively be rated at the higher level.

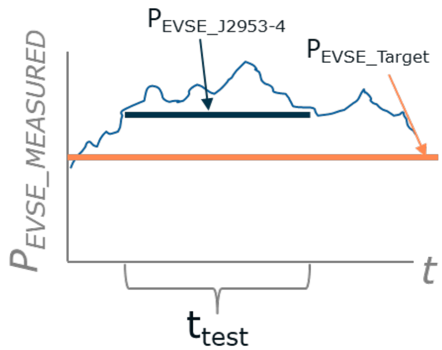


Figure 3
Example identification of SAE J2953-4 EVSE Power for higher than expected values

7. NOTES

7.1 Revision Indicator

A change bar (l) located in the left margin is for the convenience of the user in locating areas where technical revisions, not editorial changes, have been made to the previous issue of this document. An (R) symbol to the left of the document title indicates a complete revision of the document, including technical revisions. Change bars and (R) are not used in original publications, nor in documents that contain editorial changes only.

PREPARED BY THE HYBRID - EV COMMITTEE

APPENDIX A - BACKGROUND ON THE CHOICE OF THE METRIC

A.1 BACKGROUND ON THE CHOICE OF THE METRIC

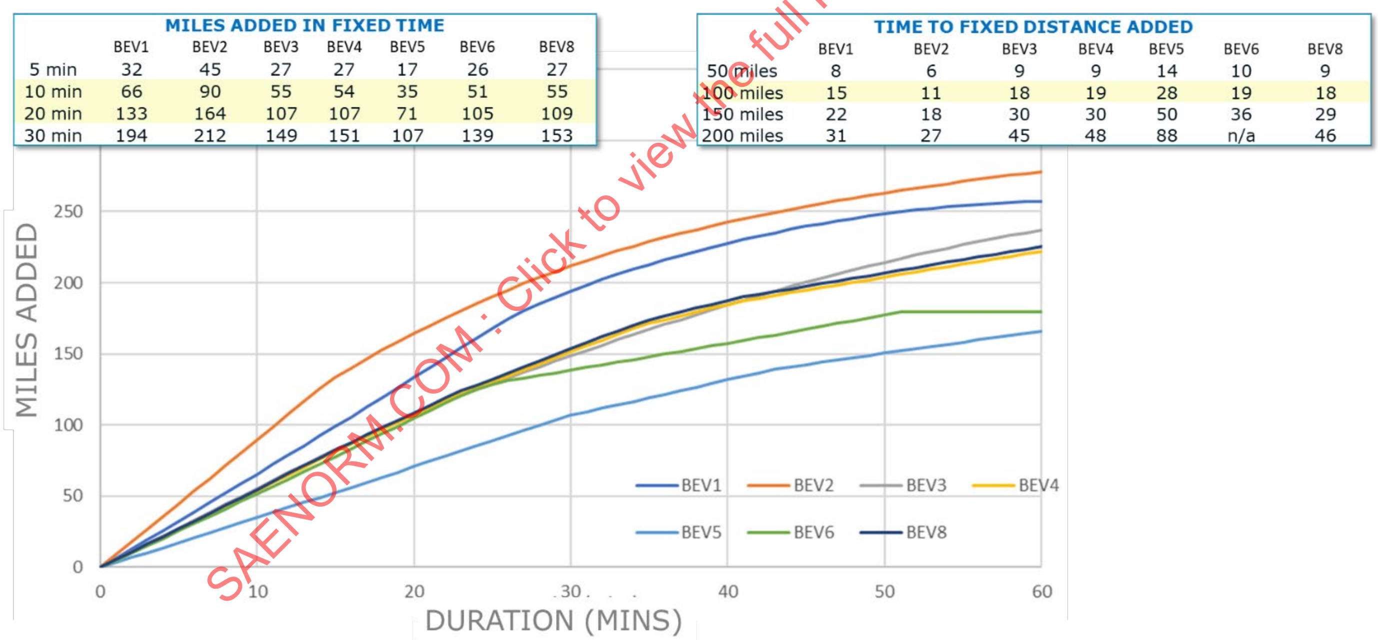
A history about the history of choosing the metric is provided to answer common and frequent questions.

Initially, five metrics were identified:

- Option 1: Time taken to replace a fixed number of miles.
- Option 2: Miles replaced in a fixed duration of time.
- Option 3: Peak miles replaced in 1 minute (later recognized to be a variation of Option 2).
- Option 4: A minutes per mile rating, averaged over a long period of time.
- Option 5: Time to an SOC level.

A.2 DISCUSSION ON OPTION 1: TIME TAKEN TO REPLACE A FIXED NUMBER OF MILES

Option 1 was eventually decided against with a committee poll in which a unanimous vote for Option 2 was recorded. While there are no data driven issues with Option 1, Option 2 was considered to be more intuitive (larger numbers are better), easier to work with as a consumer (less math), and provided a broader span of values between the fastest and slowest rates.



MILES ADDED IN FIXED TIME

	BEV1	BEV2	BEV3	BEV4	BEV5	BEV6	BEV8
5 min	32	45	27	27	17	26	27
10 min	66	90	55	54	35	51	55
20 min	133	164	107	107	71	105	109
30 min	194	212	149	151	107	139	153

TIME TO FIXED DISTANCE ADDED

	BEV1	BEV2	BEV3	BEV4	BEV5	BEV6	BEV8
50 miles	8	6	9	9	14	10	9
100 miles	15	11	18	19	28	19	18
150 miles	22	18	30	30	50	36	29
200 miles	31	27	45	48	88	n/a	46

Figure A1

A.3 DISCUSSION ON OPTION 2: MILES REPLACED IN A FIXED DURATION OF TIME

Option 2 was eventually chosen against Option 1 in a committee poll. It was considered to be more intuitive (larger numbers are better), easier to work with as a consumer (less math), and provided a broader span of values between the fastest and slowest rates.

A.4 DISCUSSION ON OPTION 3: PEAK MILES REPLACED IN 1 MINUTE

Option 3 was eventually recognized to be the same as Option 2 but with a 1 minute duration. It was generally agreed that a short timeframe such as this does not allow for reliable extrapolation (e.g., "if it charges 10 miles/min, then I only need 30 minutes for 300 miles") and is easily gamed by using thermal characteristics of the system, dropping down to a significantly lower rate after the necessary 1 minute.

The model based on actual 2019 data shows the peak variations of such a metric:

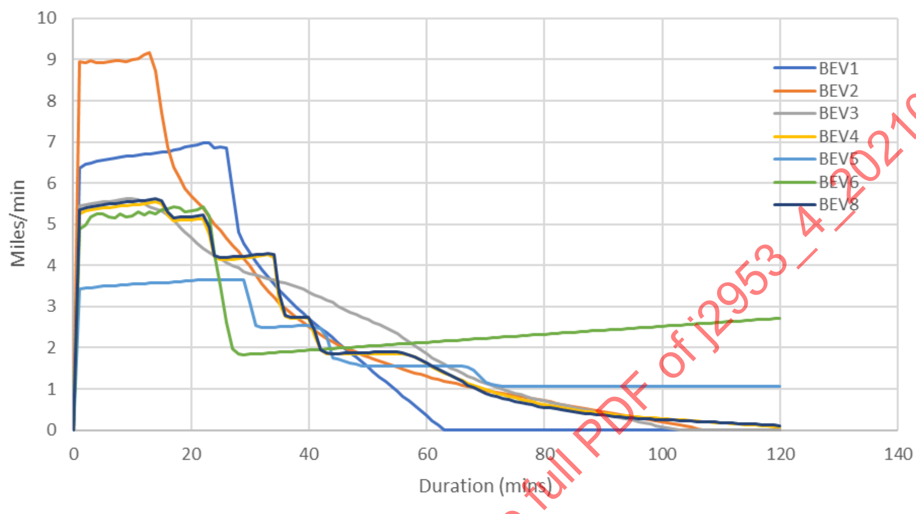


Figure A2

A.5 DISCUSSION ON OPTION 4: A MINUTES PER MILE RATING BUT AVERAGED OVER A LONG PERIOD OF TIME

Option 4 was generally felt to be confusing. It would be expressed as a miles per minute rate, but have an asterisk on it to say "but over 20 minutes" or similar. The same error in extrapolation as possible with Option 3 was expected.

A.6 DISCUSSION ON OPTION 5: TIME TO AN SOC LEVEL

Despite being the initial instinct by many people was removed from consideration because as a percent SOC value, it is relative to the size of the battery. Therefore, smaller battery vehicles can rate better with such a metric, despite providing less performance to the consumer. The following data is used as an example. This is a model based on real 2019 data.

If ranked by time-to-SOC, the vehicles would rate:

Table A1

Vehicle	Time to 80% SOC
BEV6	24 minutes
BEV1	27 minutes
BEV2	35 minutes
BEV4	45 minutes
BEV8	45 minutes
BEV3	46 minutes
BEV5	59 minutes

However, if the amount of range added in the time it takes for the fastest to 80%, BEV6, to charge to 80% is considered, it can be shown that there are other vehicles which add considerably more miles by the time that BEV6 is done with the test, and those vehicles continue to add range afterwards. The time for 10 to 80% SOC would unfairly rank BEV1 and BEV2 as lower performing than BEV6, resulting in confusion for the consumer and no help to the industry.

Table A2

Vehicle	Time to 80% SOC	Miles Add in the Time it Takes BEV6 to Reach 80%
BEV6	24 minutes	125 miles
BEV1	27 minutes	161 miles
BEV2	35 minutes	185 miles
BEV4	45 minutes	126 miles
BEV8	45 minutes	128 miles
BEV3	46 minutes	125 miles
BEV5	59 minutes	85 miles

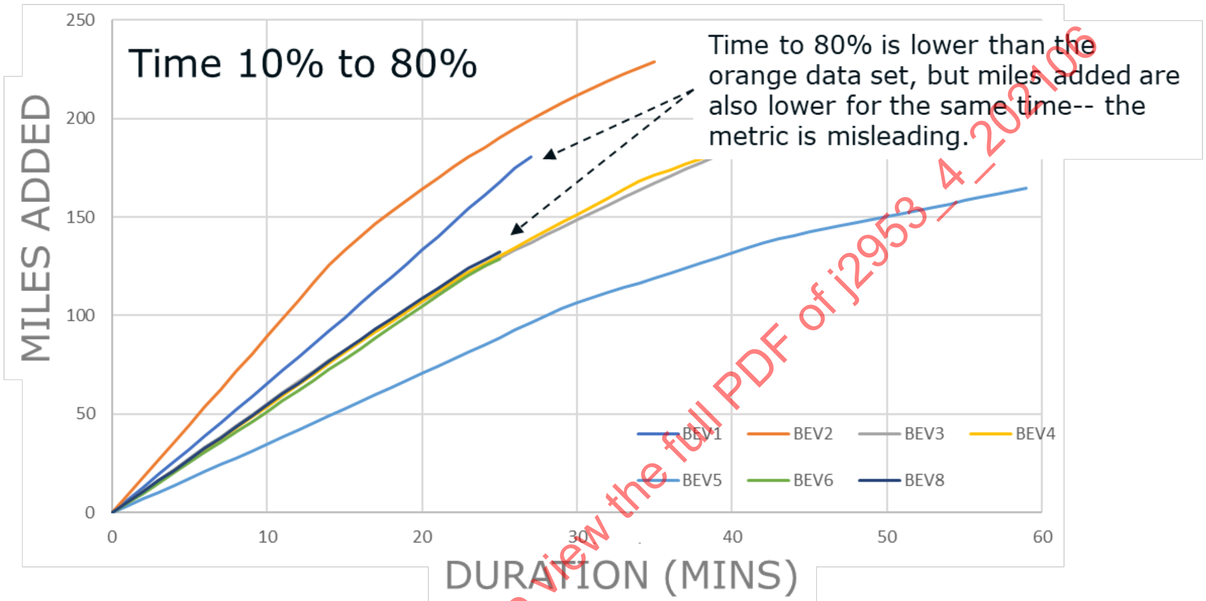


Figure A3

APPENDIX B - BACKGROUND ON METHODS TO DETERMINE RECHARGE ENERGY

B.1 MEASURING RECHARGE ENERGY

The measurement of recharge energy has many complications.

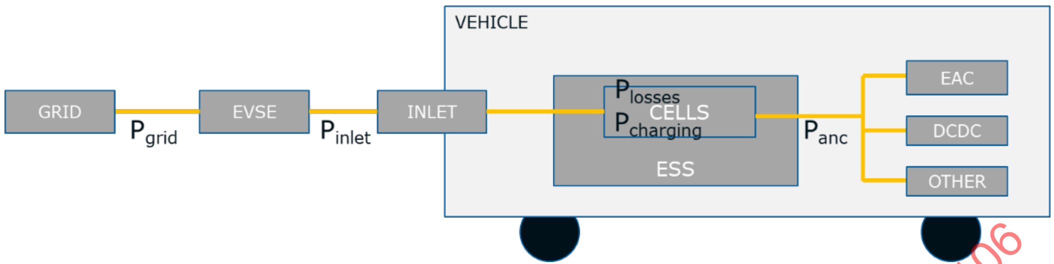


Figure B1

B.2 COMPLICATION 1: ANCILLARY LOADS

Vehicle use of ancillary loads (P_{anc}) which include the DCDC and the electric air compressor can be significant. There are vehicles on the market using 10 kW and trends towards 20 kW, even 25 kW, worth of electrical loads for cooling of the battery during this high power charging are forming. The impact of this ancillary power can be significant on the reported charge rate.

Example: Three vehicles with the same on-road energy consumption and the same battery pack, but each using different ancillary loads and charging at two different rates on the proposed test in this document for 10 minutes.

Table B1

Charging Rate	0 kW Ancillary Loads	10 kW Ancillary Loads	20 kW Ancillary Loads
200 A	42 miles/10 minutes	37 miles/10 minutes	32 miles/10 minutes
400 A	82 miles/10 minutes	77 miles/10 minutes	72 miles/10 minutes

It is clear that the vehicle designs which use less ancillary power during charging provide more value to the consumer with respect to charging rate and must be accounted for. The accounting should consider the actual usage of the ancillaries to promote designs and strategies which result in higher charging rates.

B.3 COMPLICATION 2: ACCESS TO MEASUREMENT POINTS

Trends in the design and integration of vehicle battery packs and high voltage systems are making it increasingly difficult to instrument for measurements.

- Knowledge of the distribution system is required to ensure that all relevant currents are measured.
- Access to locations, which may or may not support installation of a current sensor even if accessed, may require dismantling and even cutting of enclosures and/or cables.
- The systems are designed to prevent tampering for safety. These monitors may prevent the operation of the vehicle if modification of the system is detected. Connection of voltage sensors changes the hazards associated with the system. Furthermore, it is the recommendation of OEMs to not allow access to the HV system by untrained personnel to prevent injuries.

Access to measurement points in the EVSE faces the same hurdles as in a vehicle.

Measurement of the EVSE to PEV cable by insertion of a breakout box or similar is complicated by the use of liquid cooled cables in the EVSE for high current charging. The absence of liquid cooled cables at the vehicle inlet may result in damage to the inlet coupler. A breakout box would require the cooling system to be continued on both sides. Finally, even with this advanced breakout box, there would be no accounting for the measurement of the ancillary loads.

To address all the above issues, the acceptance of currents and voltages reported over data busses on the vehicle is promoted for this test. Battery management systems in the vehicles need to estimate the net energy into the pack as a normal operating function. The BMS and associated vehicle controllers have the ability to report that value to externally facing data bus, as is done with other values for diagnostics, and it is in the interest of the OEM to make the information available to ease range testing efforts for themselves and prevent confusion at regulatory agencies by avoiding this complication of adding measurement equipment. At this time, the same values are made available and accepted for use for the WLTP PEV range test. An effort to harmonize that aspect with the SAE J1634 PEV range test standard has begun, this charge rate test will use the results of that effort to receive values relating to the voltage and net current into the battery pack.

B.4 COMPLICATION 3: JOULE LOSSES

The net energy measured going into the battery pack is not the same as the energy added into storage in the pack.

$P_{charging}$ is integrated to measure the energy that goes into the battery that is usable later for operating the vehicle. P_{losses} result in energy that goes into the battery pack but does not result in usable energy for future use. This is primarily joule losses (heating). At high currents involved in DC charging, this heating can be a significant difference between the actual recharge rate (usable miles added over time) and a rate calculated by measuring the net energy into the battery with I and V.

Joule heating is also complicated by the significant differences in current distribution between battery packs at a lower voltage (for example, 400 V) and packs at a higher voltage (for example, 800 V). Because of series and parallel combinations of similar cells, battery packs of equal capacity but at twice the voltage have approximately 4X the joule losses at the same net battery current. This occurs because the net charging current is distributed over fewer parallel cells, increasing the current by cell by 2X (in a pack of similar capacity) and the heat by 4X due to I^2R relationship. At the same cell C rate, the heat losses are the same, but at the same pack C rate, the heat losses are higher.

A number of methods are proposed to address this.

B.4.1 Method 1: Ignore

Order of magnitude modelling was done to estimate the potential impact of Joule losses on the measured charge rate.

Model assumptions:

- 400 A constant net into the battery pack
- No limits on cell currents or C rates
- No ancillary loads
- 10 minute test time
- 3 miles/kW•h energy consumption
- Test starting at 15 miles of range (varying SOC due to varying pack sizes)
- S and P of cells adjusted to fit a grid of usable pack energy and maximum charging voltage
- 4.8 A•h cells with data based internal cell R versus SOC s and open circuit voltage versus SOC curves

The calculated miles added in 10 minutes if the joule effect is ignored shown for different battery cells in series (s-count) and different pack capacities:

		Pack Capacity					
		60 kWh	80 kWh	100 kWh	120 kWh	140 kWh	160 kWh
	96 s	76	75	75	74	74	74
battery	108 s	86	85	84	84	83	83
config	132 s	106	104	103	103	102	102
s-count	156 s	126	124	123	122	121	121
	180 s	147	144	142	141	140	140
	216 s	179	174	172	170	169	168

Figure B2

The calculated miles added in 10 minutes if the joule effect is perfectly compensated for shown for different battery cells in series (s-count) and different pack capacities:

		Pack Capacity					
		60 kWh	80 kWh	100 kWh	120 kWh	140 kWh	160 kWh
	96 s	71	71	71	71	71	71
battery	108 s	79	80	80	80	80	80
config	132 s	96	96	97	97	98	98
s-count	156 s	112	113	114	114	115	115
	180 s	128	129	130	131	132	132
	216 s	152	153	155	156	157	158

Figure B3

Finally, the percent difference from the above calculations—shown for battery cells in series (s-count) and different pack capacities.

		Pack Capacity					
		60 kWh	80 kWh	100 kWh	120 kWh	140 kWh	160 kWh
	96 s	7%	5%	5%	4%	3%	3%
battery	108 s	8%	6%	5%	4%	4%	3%
config	132 s	10%	7%	6%	5%	5%	4%
s-count	156 s	11%	9%	7%	6%	5%	5%
	180 s	13%	10%	8%	7%	6%	5%
	216 s	15%	12%	10%	8%	7%	6%

Figure B4

In all cases, ignoring the effect results in a higher calculated charging rate. While some of these data points are extreme (the red cells) and also unlikely to be implemented in a vehicle because of their very high C rates, the orange, yellow, and green areas show variability across both pack size and s-count with a linear proportional change with respect to the s-count (double the losses between a 96 s and 192 s pack configuration). This is consistent with the discussion above that joule losses are higher in similar capacity packs reconfigured for higher voltages—the per cell currents are higher.