2024 TECHNICAL REPORT

Methodology for Testing the Accuracy of Data Collected from Managed Charging Enabling Technologies

Methodology for Testing the Accuracy of Data Collected from Managed Charging Enabling Technologies

3002031024

Final Report, September 2024

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ACKNOWLEDGMENTS

EPRI prepared this report.

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This report describes research sponsored by EPRI.

This publication is a corporate document that should be cited in the literature in the following manner: *Methodology for Testing the Accuracy of Data Collected from Managed Charging Enabling Technologies.* EPRI, Palo Alto, CA: 2024. 3002031024.

ABSTRACT

The objective of this project was to perform an initial evaluation of and propose a test method for assessing the accuracy of energy data collected by electric vehicle supply equipment (EVSE) and electric vehicle (EV) telematics. The project conducted some initial exploratory testing to help guide and define testing needs. A test protocol was developed and applied to devices under test (DUTs). DUTs consisted of three EVs, three telematic providers, four EVSEs, and two EVSE data hosts. Data was collected from these DUTs and compared to energy measurements made using lab-grade instrumentation (the test standard) with NIST traceable calibration. All data collected in this report has been anonymized to alpha-numeric designators for each manufacturer's DUT. The project did not develop performance standards and was not intended to certify equipment performance.

Keywords

- EV Telematics
- EVSE Energy Measurements
- Data management Service Providers

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1 EXECUTIVE SUMMARY

The objective of this project was to perform an initial evaluation of and propose a test method for assessing the accuracy of energy data collected by electric vehicle supply equipment (EVSE) and electric vehicle (EV) telematics. The project did not develop performance standards and was not intended to certify equipment performance.

Data from three EVs, three telematic providers, four EVSEs, and two EVSE data hosts was compared to energy measurements made using lab-grade instrumentation (the test standard) with NIST traceable calibration. All data collected has been anonymized to alpha-numeric designators for each manufacturer's device under test (DUT).

Testing results summary:

- All energy measurement methods evaluated underreported energy use as measured by a lab instrument placed upstream of the EVSE.
- For AC level 2 EVSE
    - Provided a best-case measurement difference of around -1%.
    - Remote data processing systems did not handle short-duration sessions (5 minutes) consistently with measurement difference increasing to a range of from -2% to -17%.
- For DC charger
    - Provided a best-case measurement difference of -7%.
- For EV Telematics
    - Provided a best-case measurement difference in the range of from -7% to -15%.
    - Use of auxiliary loads on the EV while charging increased measurement difference to a range of from -16% to -60%.
    - Under some auxiliary loading conditions, an EV may fail to report energy use (-100% error), either completely missing the session or reporting zero energy use.
    - Remote data processing did not handle short-duration sessions (5 minutes) consistently.

While metrology incorporated into EVSE was purpose built for energy measurement, auto manufacturers have noted that existing EV metrology systems were not purpose designed to support revenue grade energy metering. This leaves open the future opportunity for EV manufacturers and managed charging providers to improve measurement accuracy. They can start by standardizing EV energy measurements, compensating for upstream losses/utilization, and further standardizing reporting. This could start with an SAE Standard for Telematics-based energy measurement, with a goal to develop a standard way for EVs to report totalized energy 1) at the vehicle inlet, 2) with the appropriate resolution, and 3) in a standard file format.

For more detailed information, the remainder of this report addresses the project background, test setup, exploratory testing, project barriers and lessons learned, test protocol development, test results, and conclusions with future recommendations.

2 PROJECT BACKGROUND AND VALUE

Remote EVSE data collection and data collection via EV telematics systems can be used to monitor and manage the performance and operation of EVs in real-time. Potential utility benefits include:

- The ability to collect EV energy use data to better integrate the vehicles with the electric grid.
- Expanded potential for utilities to offer EV programs.
- Customers participation in programs without need of added technology.
- Eliminate the need for installation of an extra utility meter.

Managed charging programs use data from vehicle telematics and EVSE today. To use telematics or EVSE data at scale likely involves developing new standards or best practices so that utilities can provide positive customer experiences and meet regulatory expectations. Automakers have also recently signaled interest in a nationwide approach on the use of vehicle data in utility programs[1].

Pursuant to the New York Public Service Commission's Order,[2] the Joint Utilities of New York[3] hired EPRI to conduct a project that measures and evaluates the reliability and accuracy of managed charging-enabling devices. The objective of this project is to test and propose a method that includes electric vehicle supply equipment (EVSE) and electric vehicle (EV) telematics. This project is an assessment of the technology and recommended test—not a performance standard or certification. This project has not considered and does not conclude that devices need to meet +/- X% accuracy against this test method.

[1] Alliance for Automotive Innovation, Vehicle Grid Integration: The Convergence of the Automotive and Electric Power Industries, July 2024. Available at: https://www.autosinnovate.org/posts/papers-reports/VGI%20White%20Paper_2024.pdf

[2] Case 18-E-0138, *Proceeding on Motion of the Commission Regarding Electric Vehicle Supply Equipment and Infrastructure* (EVSE Proceeding), Order Approving Managed Charging Programs with Modifications (issued July 14, 2022) (Order), Ordering Clause No. 6, p. 58-59.

[3] The Joint Utilities are Central Hudson Gas & Electric Corporation, Consolidated Edison Company of New York, Inc., New York State Electric & Gas Corporation, Niagara Mohawk Power Corporation d/b/a National Grid, Orange and Rockland Utilities, Inc., and Rochester Gas and Electric Corporation.

3 TEST SETUP

For typical accuracy testing, the calibrated standard measurement meter, the meter which all other measurements will be compared for accuracy, would be placed at the same measurement point as the device-under-tests (DUTs). However, because the EV's measurement components for charging are not accessible, this project assessment is comparing the measurement differences from a calibrated standard measurement meter placed upstream of the DUT. Two upstream measurement points were chosen, one at the point of common coupling (PCC), representing the typical location of a utility revenue meter (referenced as meter one (M1)) and one at the EV charger port (referenced as meter two (M2)). Between the EV's measurement sensor and our standard metering locations are EV loads and wiring losses that will consume power; therefore, instead of reporting a "percent error", this assessment will be using the term "percent difference" to reflect this configuration.

The test setup for this project consists of equipment and metering points as shown in Figure 3-1 below:

Metering Point	Test Equipment
	Pacific Power 62 kVA Power Source
M1	Hioki PW6001 Power Analyzer
	Power In Distribution Terminal
Ms	EVSE Device Under Test (DUT) with Internet Remote Communications
Mr	EVSE Data Host DUT
	Power Out Distribution Terminal
M2	Hioki PW3390 Power Analyzer
	Charge Connector
Mv	EV DUT with OEM provided remote communications
Mt	Telematics DUT

Test Setup

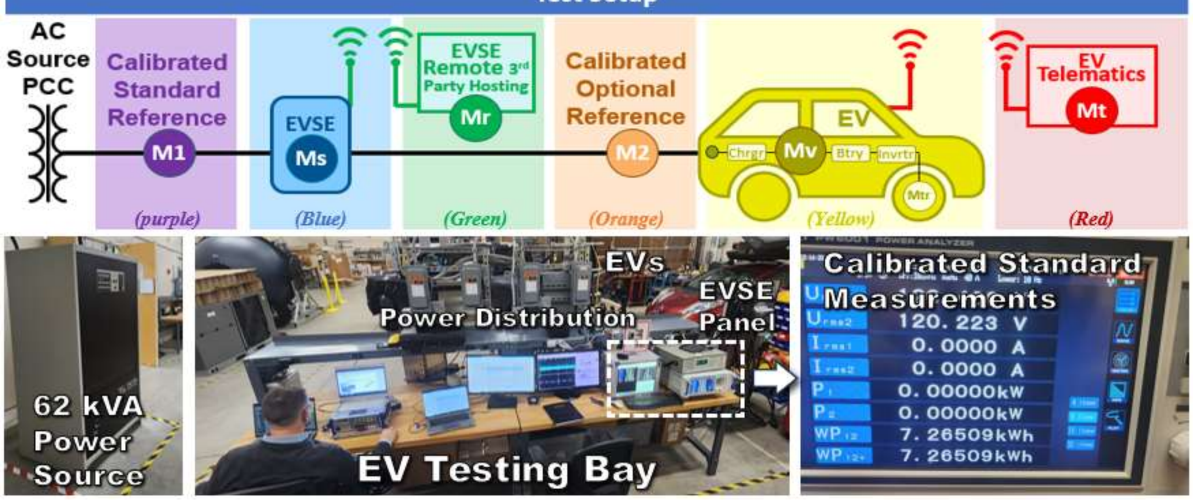


Figure 3-1
Test Setup and Monitoring Points

4 EXPLORATORY TESTING

This section describes the preliminary tests that were conducted to understand how the DUTs presented measurement data and responded to certain timing and conditions from general test methods. Later sections of this report (i.e., Test Protocol Development and EV and EVSE Test Results) discuss the latter stages of the project that built upon this initial exploratory testing.

EV Metrology and Remote Access

For engineers performing standard test, sources of charging data from the EV are somewhat limited or constrained. The typical EV dashboard provides a state of charge (SoC) percentage or miles of range. Some EVs may provide an actual power or energy value, but it is only given as 1 or 2 significant figures in kilowatt-hours (kWh). This testing was focused on getting at least 1 watt-hour (Wh) of resolution with 4 significant integer figures—for example 1,234 Wh.

On-board diagnostics (OBD) are a potential source of data that might provide the resolution needed. However, many EV manufacturers do not publicly release the parameter identifiers (PIDs) needed to address the OBD and obtain those values. Lists of PIDs are available online by the public, but they were obtained through reverse-engineering and not certified by the EV manufacturer as being accurate. It should also be noted that an OBD port is not a mandatory feature on an EV.

The SoC is typically stated as percentage from 0 to 100%, representing an “empty” or “full” battery respectively. To convert SoC values to energy values, the battery capacity that the SoC is based on must be known. The value may be derived from the total battery capacity of the EV or the total usable capacity of the EV. As battery capacity will decrease over time due to battery degradation, how the relationship of SoC to energy might change is an unknown.

For this project, the energy measurement at the EV was derived from the SoC with the following equation.

$$Wh = (\%\,SoC^{End} - \%\,SoC^{Start}) \times (Utilized\ Battery\ Size\ in\ Wh)$$

Note that in order to obtain an accurate integer value, the SoC had a start and end measurement taken from the EV display at the point at which it changed from one value to the next as shown in Figure 4-1.

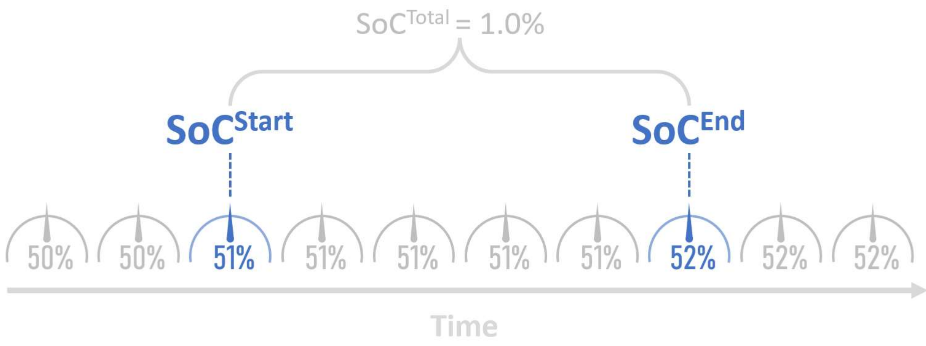


Figure 4-1
Illustration of using an EV dashboard display to collect the start and end points of SoC data.

Shown in Table 4-1 is a list of EVs used for this project. All the EVs chosen were required to have an established telematics data collection system for charging data in place. Only one EV provided an application programming interface (API) for third party hosting, the others were provided by the EV original equipment manufacturer (OEM).

Table 4-1
List of EVs used for the project and the source of data.

EV ID	EV1	EV2	EV3
Local Data	SoC Display	SoC Display	SoC Display
Telematics	OEM Provided	OEM Provided	3rd Party Host

EVSE Metrology and Remote Access

Some EVSEs provide measurement data through local built-in displays. Many also support smartphone apps or cloud-based platforms for users to collect detailed charging information. Some offer APIs that allow for third parties to access and process data remotely. As with the local EV data, some EVSEs did not provide the resolution or significant figures needed for measurement accuracy testing. Obtaining precise data required working with either the OEM or directly with the third-party data host.

Shown in Table 4-2 is a list of EVSEs used for this project. All the EVSEs chosen were required to have at least some form of cloud-based storage and access and to present data with at least 1-Wh resolution.

Table 4-2
List of EVSEs used for the project, the type of EVSE, and source of data.

EVSE ID	S1	S2	S3	S4
EVSE Type	Level 2	Level 2	Level 2	DCFC
Local Data	Smartphone App	Smartphone App	Smartphone App	Built-in Display
Remote Data	3rd Party Host	3rd Party Host	3rd Party Host	OEM Cloud-Based

Initial Tests and Lessons Learned

Some of the initial tests used to guide the test protocol development are shown in Table 4-3. The primary purpose was to determine if the hypothesized conditions were significant enough to impact telematics measurements and warrant inclusion in the final test protocol. Two tests showed significant impact, the duration of the test and the application of auxiliary loads onboard the EV during charging.

Table 4-3
Preliminary test for guiding test protocol development.

Exploratory Test	Purpose	Summary Result
Background Loading	With no charging and auxiliary loads from EV, determine if background loading exist and level of contribution to accuracy.	No significant loading that impacts telematics accuracy. In milliamps from EVSE.
Duration	Determine if duration of the charge period affect accuracy.	Significant impact to measurement and telematics timing.
Cold Environment	Determine if charging a cold vehicle affects accuracy.	No significant impact to telematics.
208V System	Determine if powering with a 208 line-to-line voltage from a three-phase system impacts accuracy.	No significant impact to telematics.
Aux w/Charging	Determine if auxiliary loads during charging affect accuracy.	Significant changes to telematics accuracy exists.
Harmonics	Determine if background harmonic voltage impacts accuracy.	No significant impact to telematics.
Interruptions	Determine if momentary interruptions during charging impacts accuracy.	No significant impact to telematics.

Durations Results

Shown in Figure 4-2 are preliminary test results from EV1. Each test is shown on the X axis and was administered three times. The bar chart shows the variation (maximum, median, minimum) of those three iterations. Most tests varied between 2% to 5%; however, the long test provided better precision, less than 0.5%, than all the other tests. The long test was 3-hours, while the other tests were 5 to 15 minutes. This helped determine that our test duration needed to be increased to greater than 15 minutes. Additionally, some telematics providers stated that accuracy and precision for their systems would be better with durations greater than 30 minutes, and that the minimum time between charging sessions should be between 15 to 30 minutes. No reason was given why this delay should be built-in to the testing, but hypothetically this could be due to data collection sampling rates. For protocol testing phase discussed later in this report, 1-hour was selected for test duration with 30 minutes between tests.

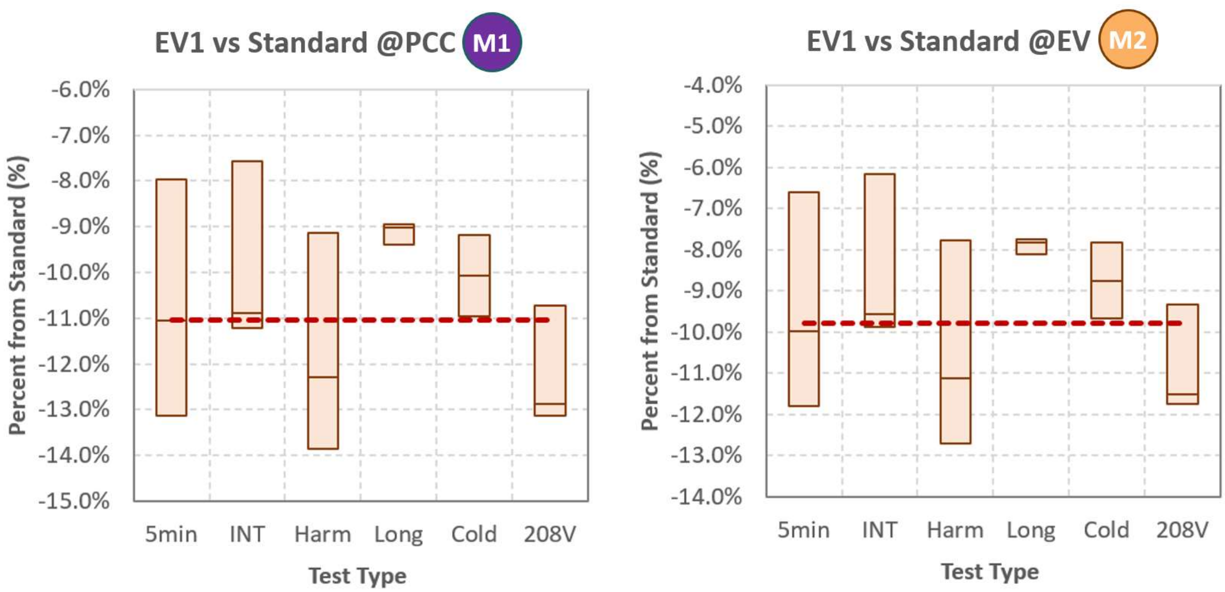


Figure 4-2
Preliminary test results of exploratory testing that highlighted the need for longer testing to get better precision.

Auxiliary Loads Impact

Auxiliary loads in EVs can include the headlights, infotainment systems, cabin cooling and heating, vehicle electronics systems, and external electric loads plugged into accessory outlets provided in the EV. Depending on the design of the EV, these auxiliary loads may draw power from the EVSE or from the high-voltage (HV) battery in the EV. Depending on the location of the EV's current transducer(s), the results of the EV charging data can be impacted (i.e., an EV's kWh measurement may omit the energy used for auxiliary loads).[4] Shown in Figure 4-3 is a generic illustration demonstrating how current transducer placement in an EV might change the measurement results. The EV on top has the current transducer located near the high-voltage (HV) battery that is using 90% of the total EV load, but that transducer is downstream of the path to the auxiliary (aux) loads that are using 10% of the total load. The EV on the bottom of the illustration has the current transducer located upstream of both the aux loads and the HV battery. Here, it is measuring 100% of the total load of the EV.

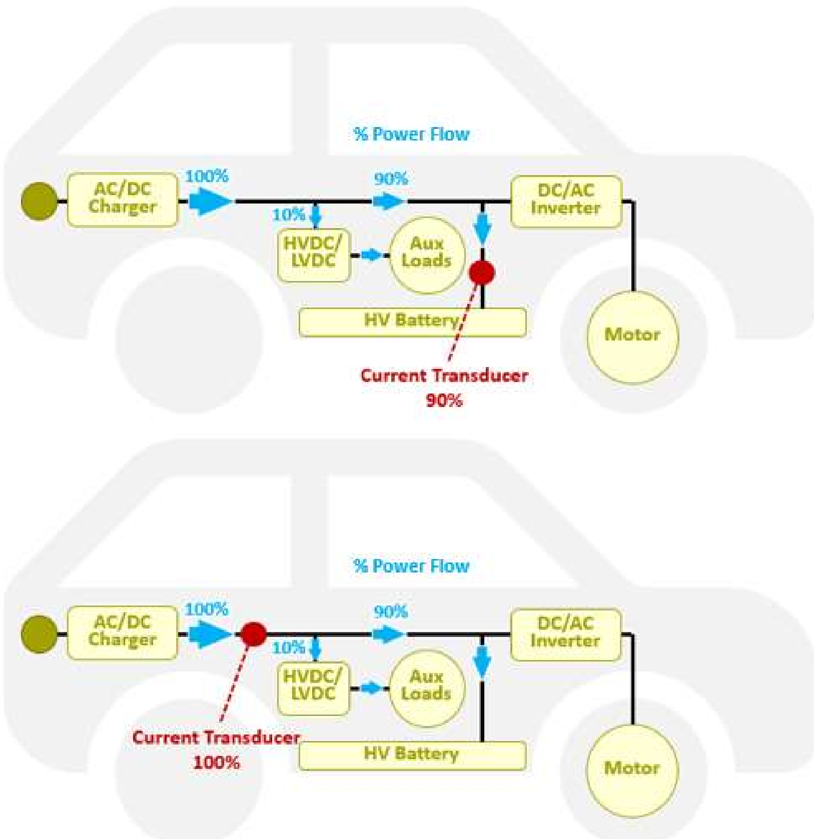


Figure 4-3
Generic illustration of how the placement of energy measurement transducers can impact accuracy.

[4] Theodore Bohn, Cross Correlation of EV Charging Measurements, April 2023, available at: https://documents.dps.ny.gov/public/Common/ViewDoc.aspx?DocRefId=%7bA045BF87-0000-CA14-B513-198477C68BF3%7d

5 PROJECT BARRIERS AND CHALLENGES

During this project there was one primary challenge (participation) and a few secondary challenges.

Participation Challenges

- EV Manufacturer Participation
  - Some manufacturers did not have vehicles with completed telematic capabilities in place.
  - Some manufactures are still working on their own data agreement processes.
  - Some manufacturers were not comfortable using data outside of its intended purpose. It was designed for vehicle operations, not energy utilization metrology.
  - Some data agreements between legal teams took months to establish.
  - Some manufacturers simply did not have vehicles to provide, which lead to the challenge of EPRI establishing agreements with private EV owners to obtain test EVs.
- EVSE Manufacturer Participation
  - Due to high cost, an option to rent a DC fast charger was pursued; however, by the time a lease agreement was put into place by legal teams, the company changed owners and lost interest in participating.
  - All other EVSEs where purchased, including three level-2 and a portable DC fast charger.
- Telematics Participation
  - Only one of the EV manufacturers currently have an API that telematic providers can use. This resulted in using one 3rd party EV telematics provider.
  - Some EV manufacturers have blocked access to telematics data for 3rd party providers.
- EVSE 3rd Party Hosting Participation
  - Only one EVSE 3rd party hosting provider was interested in participating in the project.
  - Was more cost effective to work with a utility that had an existing contract with the provider instead of contracting directly.

Secondary Challenges

- Logistics of obtaining multiple vehicles and having them shipped to the EPRI lab facility in Knoxville, TN.

- Logistics of obtaining and installing charging equipment in the EPRI lab to support testing.

- Along with the participation delays, having to conduct longer duration tests to improve data quality extended the timeline of the project.
- Data formats between different data sources needed conversion; for example, one 3rd party host provided power and demand data instead of energy data.
- Some initial forms for data did not provide enough significant figures for valid accuracy comparison.

6 TEST PROTOCOL DEVELOPMENT

The test protocol developed as part of this project is provided in Appendix A, (Test Protocol for Measurement Accuracy of EV Charging Telematics Systems). The intent of this protocol is to develop a recommended practice for assessing the energy measurement accuracy of telematic systems for electric vehicle charging, as they are presented today. Additionally, this document addresses the conditions, instruments, and methods for obtaining reliable measurements for EV charging data for comparing to telematics. As manufacturers and telematic providers make changes to optimize data collection and accuracy, this test protocol will need revisions. This protocol should be presented to EV standards organizations as a first-order draft so a wider set of industries including EV manufacturers, telematic providers, and utilities can further contribute towards standardizing measurements.

7 EV AND EVSE TEST RESULTS

The following are test results using the test methods developed during this project. Color coding and metering-point labels (Mx) in plots will follow the coding used in the test setup illustration shown below in Figure 7-1.

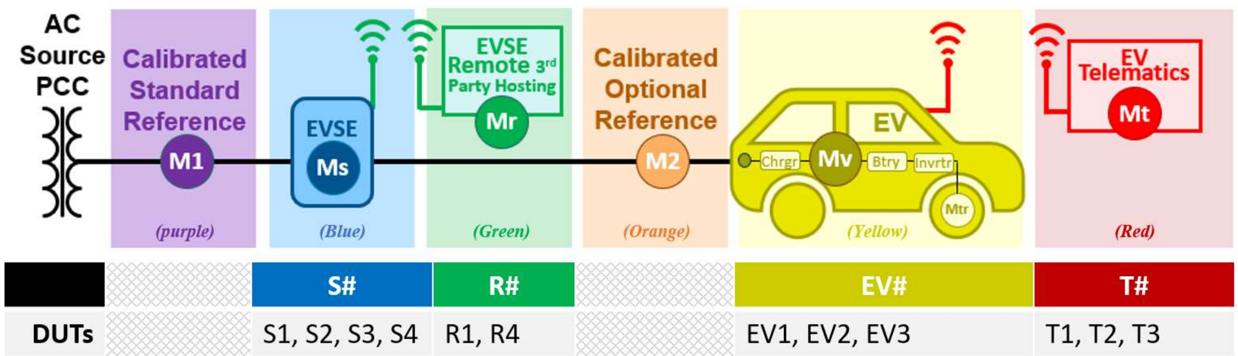


Figure 7-1
Alpha-numeric designators of DUTs and their corresponding equipment for the project.

EV Basic ΔSoC Charging Test – Telematics Energy and EV SoC

Shown in Figure 7-2 are the percent differences between each telematics and EV DUT compared to the standard measurements at PCC (M1 in purple) and at the EV (M2 in orange). Three tests were conducted for each DUT that makes up each individual plot of minimum, median, and maximum accuracy. Some key observations include the following:

- The telematics from T1 presented the highest percent difference from both standards, followed by T2 and then T3.
- T3 did not present a large difference (less than 1%) with each standard measurement; however, the telematics provider did report that a 7% compensation was used for upstream losses and utilization for this specific EV. EV3 ΔSoC accuracy measurements in the same figure did not reflect this 7% drop—it shows -1.32% at the PCC.
- The EV measurements that were derived from ΔSoC were within 1-2% of the telematics, except for EV2 compared to T2 presented a >6% variation from one another.

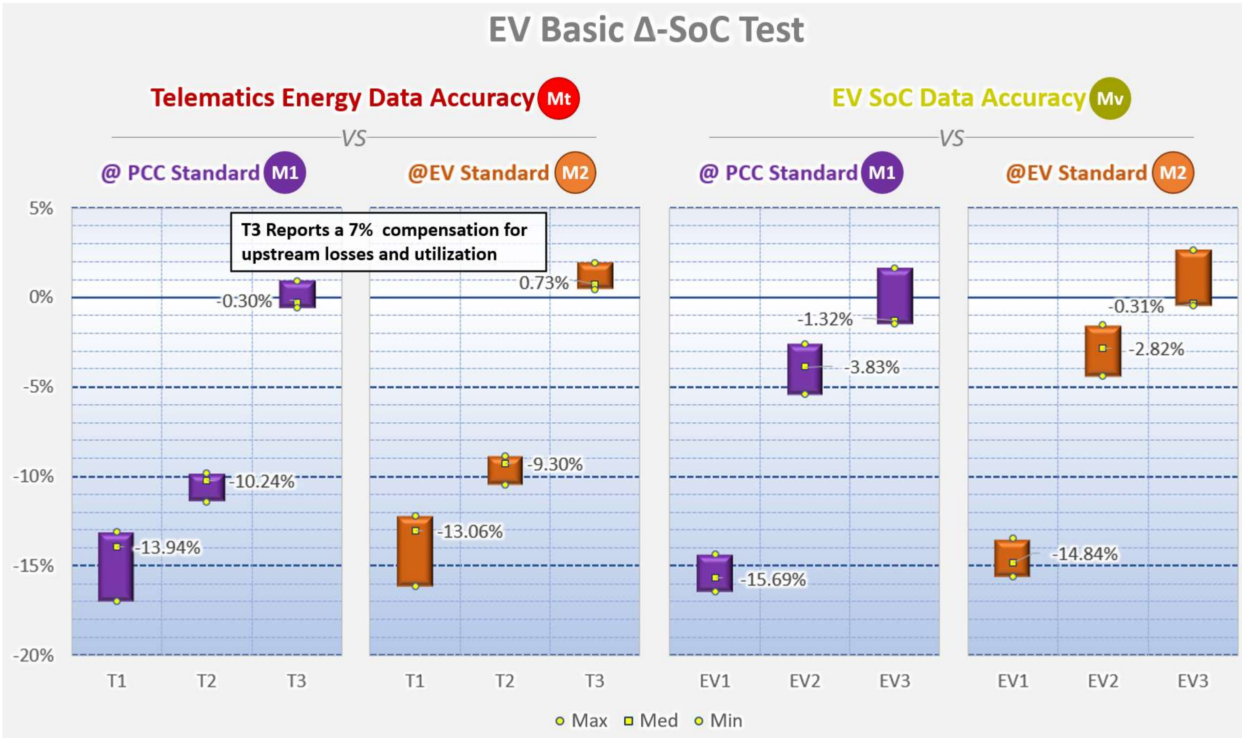


Figure 7-2
Telematics Energy Data Accuracy vs. EV SoC Data Accuracy.

EV Basic ΔSoC Charging Test – Telematics Energy and Telematics SoC

Two telematic providers provided SoC^{Start} and SoC^{End} data, T1 and T2. As stated in the test protocol, the ΔSoC multiplied times the battery capacity is used for this energy value. Shown in Figure 7-3 is the same telematics energy results from the figure above compared to the results derived from the telematics SoC data. A key observation:

- For both T1 and T2, when deriving the energy measurement from the telematic SoC values, the percent difference is significantly less than the telematics energy measurements. About ~4% variation for T1 and ~6% variation for T2.

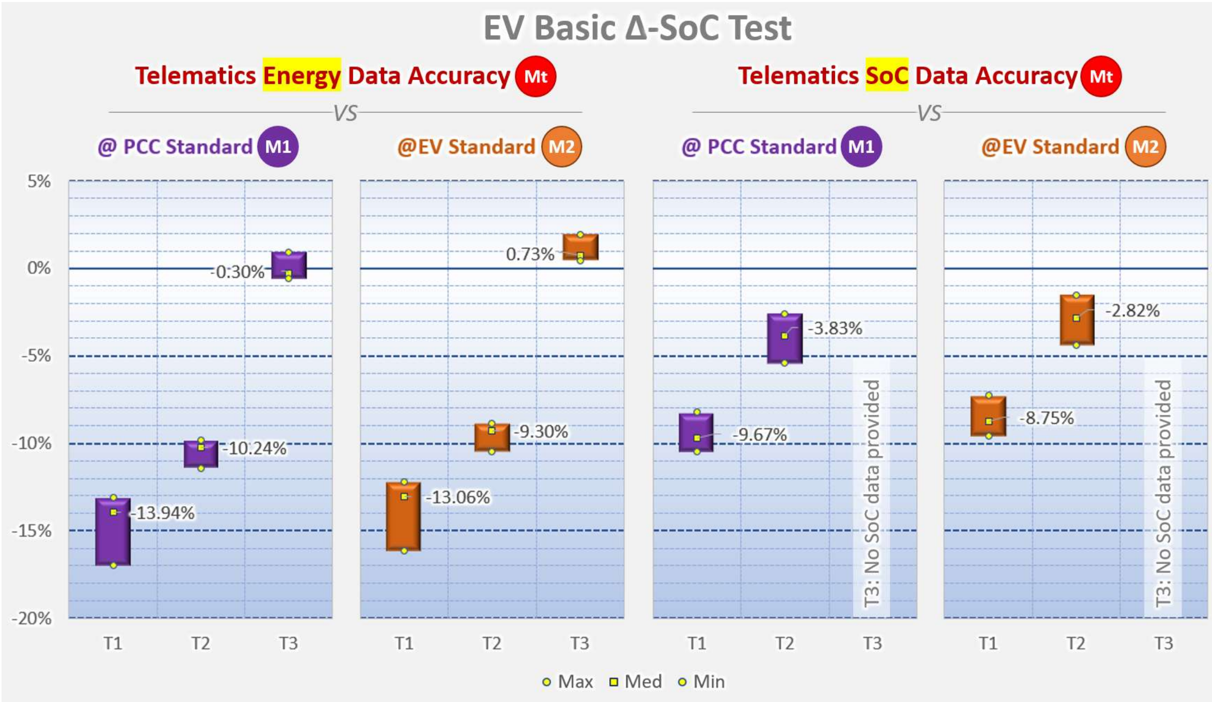


Figure 7-3
Telematics Energy Data Accuracy vs. Telematics SoC Data Accuracy.

EV Basic ΔSoC Charging Test – Telematics Energy and EVSE Remote Hosting

For EV testing, the same EVSE and third-party remote host was used for each test (S3 & R1). Shown in Figure 7-4 is the measurement accuracy results of the EVSE remote compared to the same telematics energy data above. A key observation:

- The EVSEs remote host present significantly less percent difference than the EV telematics.

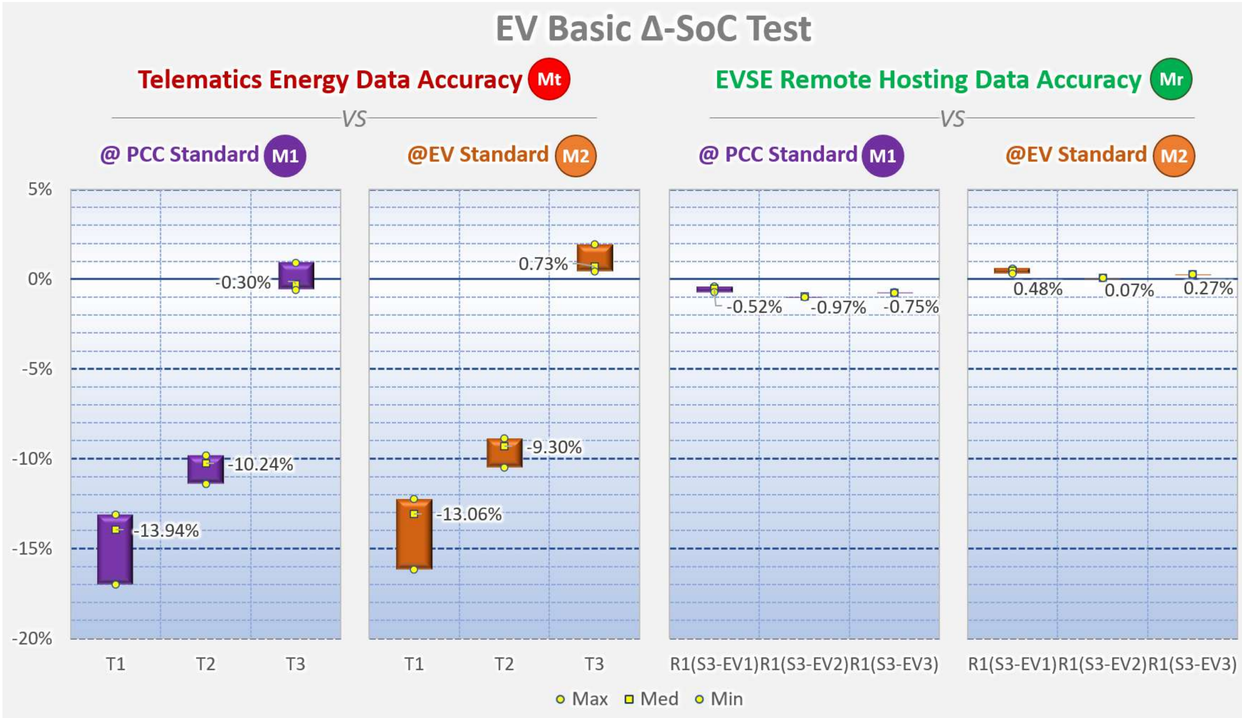


Figure 7-4
Telematics Energy Data Accuracy vs. EVSE Remote Hosting Data Accuracy.

EVSE Basic Charging Test

For EVSE testing the same EV was used for each test (EV2). The remote host (R1) provided measurement results in average 15-minute demand power, which had to be converted to energy. Note, that if two charge sessions occurred within a 15-minute period, this data arrangement would not allow one charge session to be distinguished from the other—resulting in needing to divide energy and effect accuracy. Shown in Figure 7-5 is the measurement accuracy results of the EVSE and the EVSE Remote Host compared to the standard measurements (M1 and M2). Some key observations include:

- EVSE reported data is more consistently accurate compared to EV telematics reported data.
- The difference between the EVSE and the Remote Hosting is not significant and in some cases are the same value.
- Each AC L2 EVSE (S1,S2, & S3) presents about 1% difference between the PCC standard measurement (M1) and the EV standard measurement (M2). This suggests the power drop/utilization between the two measurement points are about the same between these EVSEs.
- The DC fast charger (S4) presented a significant difference in accuracy (~7%) compared to the other AC L2 EVSEs. Given the difference between the PCC point (M1) and EV point (M2). This suggests the power drop/utilization of the DCFC is much higher than the AC L2 EVSE. Note: Many DCFC are public and covered by NIST standards for energy measurement and billing.

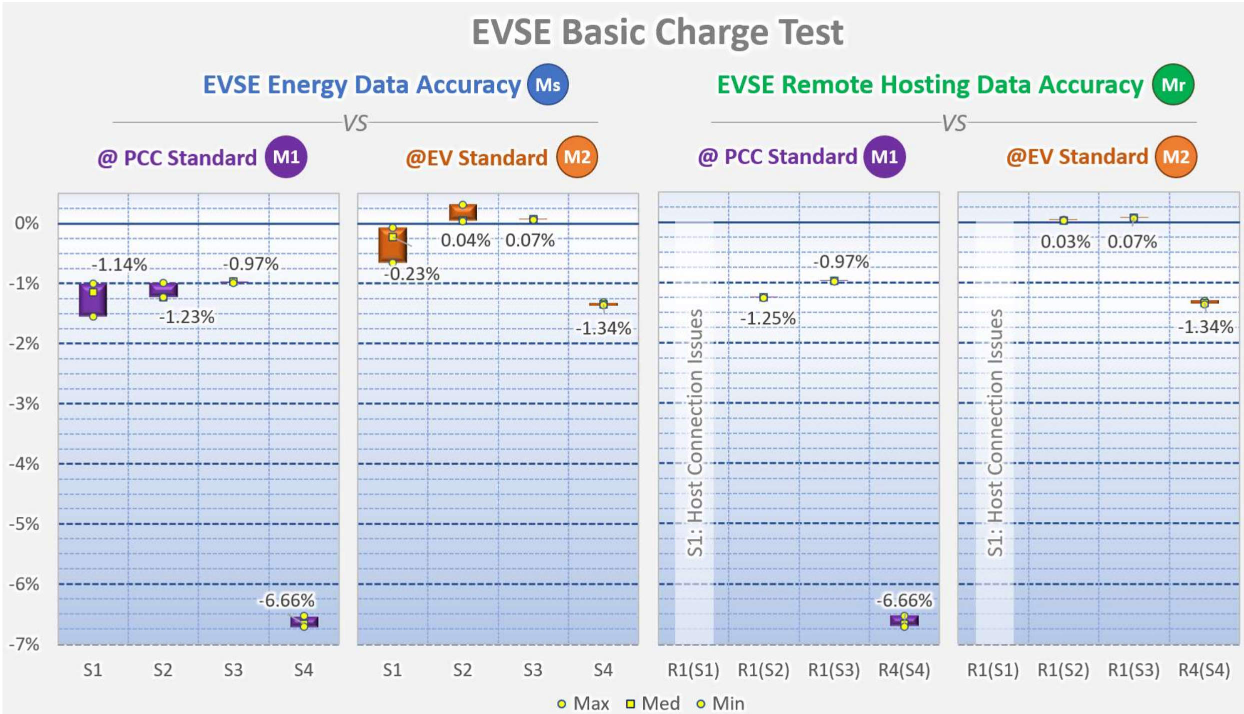


Figure 7-5
EVSE Energy Data Accuracy vs. EVSE Remote Hosting Data Accuracy

Auxiliary Load Impact Test

Shown in Figure 7-6 are accuracy results with three different tests of charging with auxiliary loads active. The auxiliary loads applied during testing consisted of EV heating or air-conditioning load. Tests were defined as "net positive" – when charging power was greater than the auxiliary load power, or "net negative" – when the auxiliary load power was greater than charging power. The "full charge" test was defined as the EV completing a full charge with auxiliary load applied. See test methods in appendix A: Test Protocol, for more details on test method. Some key observations include:

- For the overall collection of tests, each telematics provider had significant error in captured charging data in the presence of auxiliary loading.
- The Full Charge test presented the greatest impact to accuracy across all telematics, followed by Net Negative, and then Net Positive.
- During the Full Charge test, T2/EV2 spent a longer period in applying a completed charge than the other vehicles, resulting in what appears to be better accuracy. Had the vehicle fully charged sooner, the accuracy would have been close to the same as the other EVs.

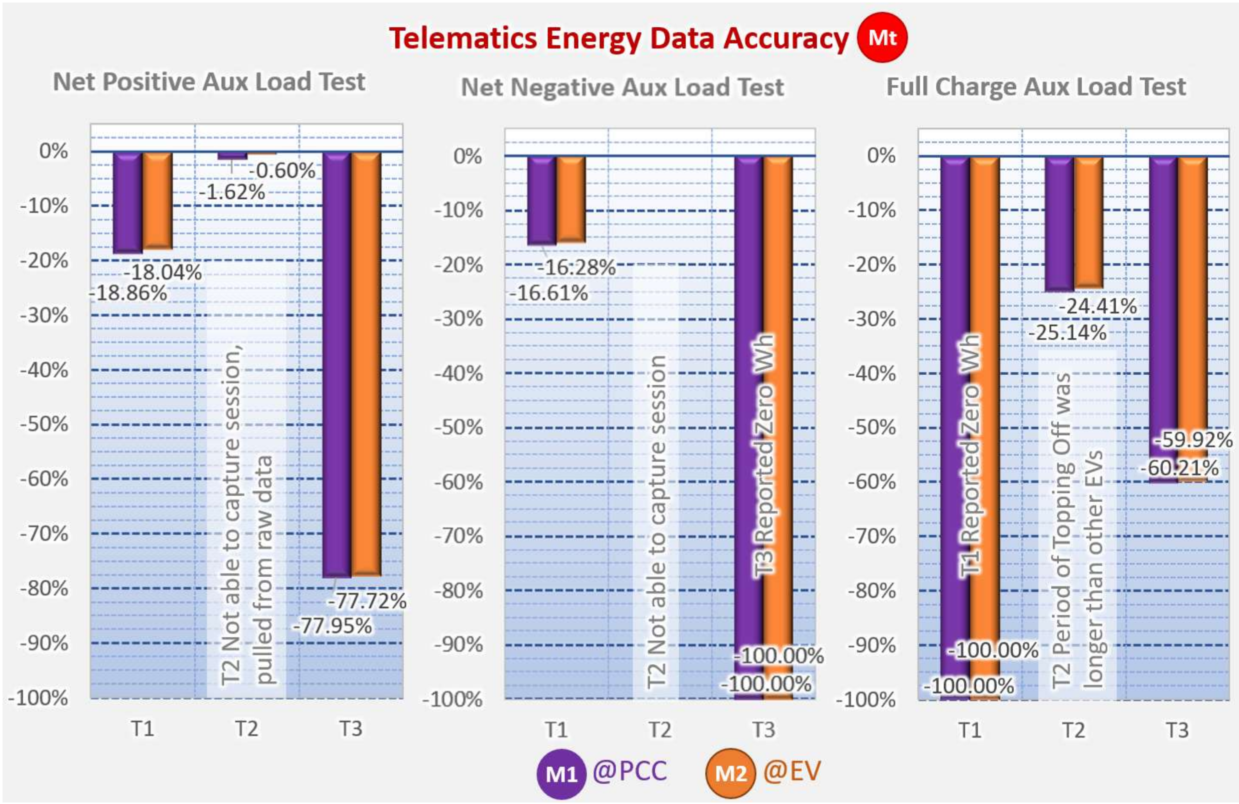


Figure 7-6
Telematics Energy Data Accuracy for Auxiliary Load Testing

Short-Term Charging Test

Early on in exploratory testing it was apparent that some telematics and remote host providers needed 15 to 30 minutes of session length to capture data accurately. Still, the short-term test was kept in place to determine the impact. This test mimics what is commonly called a "burp" charge. Shown in Figure 7-7 is the average result of three consecutive short-term tests of 5 minutes of charging with 1 minute of idle time between charges. Some key observations include:

- T2 and T3 telematics systems were not able to capture charge session data. Hypothetically due to the short time interval of testing.
- T1 was able to capture the charge session, but the percent difference was greater than 50%.
- T1 also provided SoC data, and like the basic charging test, the percent difference values were more accurate than the energy data.

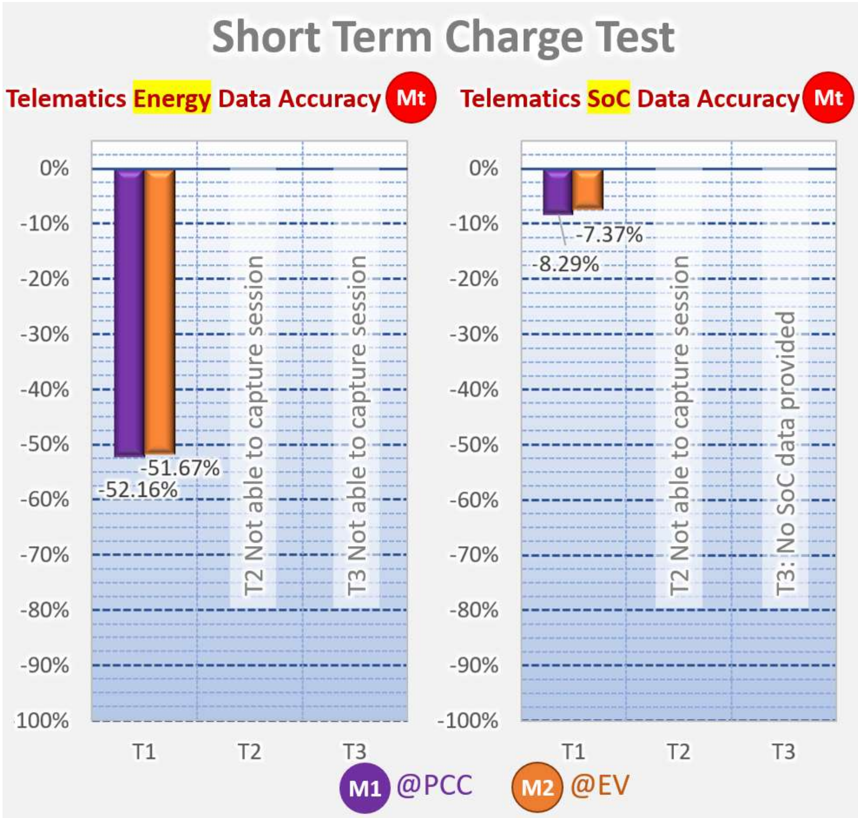


Figure 7-7
Telematics Energy Data Accuracy for Short-Term Charging Test

EVSE Short-Term Charging Results

This test is the same as the previous test except these are the results for the EVSE measurements. Some key observations include:

- As with previous EVSE test results, the average results were within 1%.
- The EVSE Remote Host presented an increase in inaccuracy, primarily with the test with EV3 (7%-17%). This was primarily due to each of the three tests for EV1 and EV2 having close to the same Wh value (within 2%), while EV3 had one test that had a one lower Wh result (20% lower). This is due to the 15-minute demand period sampling by the remote host and the charge sessions overlapping in the period.

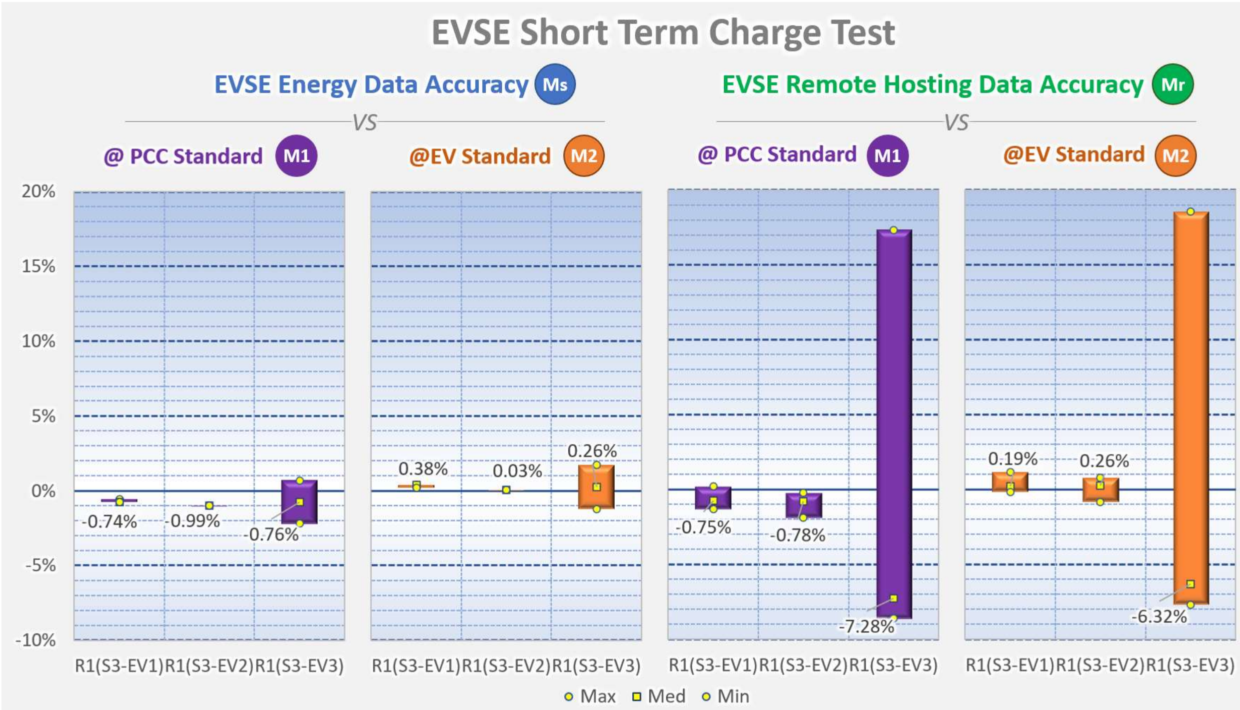


Figure 7-8
EVSE Energy Data Accuracy vs. EVSE Remote Hosting Data Accuracy for Short Term Charging Test.

8 THOUGHTS ON ENERGY MEASUREMENT VIA EV TELEMATICS

In order to calculate Energy (usually expressed in kWh), you must measure voltage and current—used to calculate power—and time. The accuracy of each of those basic measurements and the calculation method used to analyze the data influence overall accuracy of an energy measurement.
An energy measurement must be related to time in two ways:

- The time interval that the energy represents (how long)
    - This can be a fixed time interval, such as 15-minutes.
    - This can be event based—such as a “charge session”.
- The time of occurrence of this time interval (when)
    - Over what time period was this energy measured?
    - Can be a fixed time interval where the start or end time is known.
    - Can be a “session” where start time and end time are recorded.

Energy measurement methods for electric utilities have been standardized so that they can be used for billing purposes. In particular, where and how the energy is measured and how time is related to those energy measurements has been standardized.
Note that EVSE energy measurement systems benefit from this standardization:

- The hardware added to EVSE for energy measurement was purpose built to measure energy.
- Chipsets (that is, the electronics) that support energy measurement are available.
- For the EV, it is unlikely that the telematics system was structured to make the sort of energy measurement that would be typical of an electric utility.
- Where and how you measure voltage and current on a vehicle is not standardized.
    - What loads are included in this measurement is not standardized.
    - The accuracy of these measurements and the resolution of the data is not standardized.
    - The time interval at which data is taken is not standardized.
- How time is to be measured and reported is not standardized.
    - These systems generally report session-based data but may also include time stamped data values.
    - What constitutes the start and stop of a session is not standardized.
    - How often data is measured (time interval) is not standardized.
- Many vehicles report changes in battery state of charge (SoC) and not a direct energy measurement in kWh. The meaning of SoC can change with battery age, temperature, general state of health. How SoC is reported and measured is not standardized.
    - SoC is a property of the vehicle’s battery, but not all electrical loads on the vehicle may be included in that measurement.

The energy measurements reported by the vehicle, or calculated from vehicle provided data in general, were not developed to report energy at the vehicle inlet.

- The "point of measurement" is not well defined.
- What vehicle loads are or are not included is not defined.

Data reporting from a vehicle is not standardized.

- What data is reported?
- How often?
- Resolution of measurements.
    - Number of significant digits maintained.
- Data format.
- Time stamp or interval format.
    - What time zone is used?
    - How is date reported?

9 CLOSING AND FUTURE RECOMMENDATIONS

EVSE Energy Measurement

EVSE metrology provided energy measurement differences of less than 1% but struggled when session timings were short. Industry may benefit from developing standards for session-based energy reporting from EVSE.

Addressing Energy Measurement via EV Telematics

Basic accuracy for most electric utility measurement systems can vary. For revenue-grade accuracy this can be 0.2% to 0.5%, while non-revenue grade can typically vary from 1% to 3%. The results from this project show that measurements taken from telematics can vary beyond those levels when not compensated for losses and utilization of power from the PCC to the EV. There are opportunities to improve the accuracy of EV telematics, for example, by giving guidance to EV manufacturers on methods in standardizing measurement and reporting to address the observations presented in this report. Manufacturers will need to work together to determine what measures to take in improving accuracy, whether it be standardizing the placement location of measurement transducers or working towards uniform sampling intervals. From the results presented in this study, there are losses and utilizations of power between the PCC and EV. Telematics data providers will need to determine the need for compensating losses, how much that compensation will be, and what the method will be in determining it.

A potential path to address these observations involves developing a standard for telematics-based energy measurement. This effort would have a goal of establishing a standard method for vehicles to report totalized energy **at the vehicle inlet** and **in a format usable by electric utilities and third parties**. Such a standard would need to cover elements such as:

- Requirements for data formatting and reporting.
  - Energy data
  - Time data
  - Session data
  - File formats
  - Measurement interval
  - Data storage and retention
- Ensuring that all vehicle loads are accounted for in energy measurement (energy measurement referenced to the vehicle inlet).
  - This might include standard methods for inferring vehicle inlet energy from other onboard EV data sources.
  - Might include correction factors to account for wiring or other losses.
- Numeric resolution requirements.

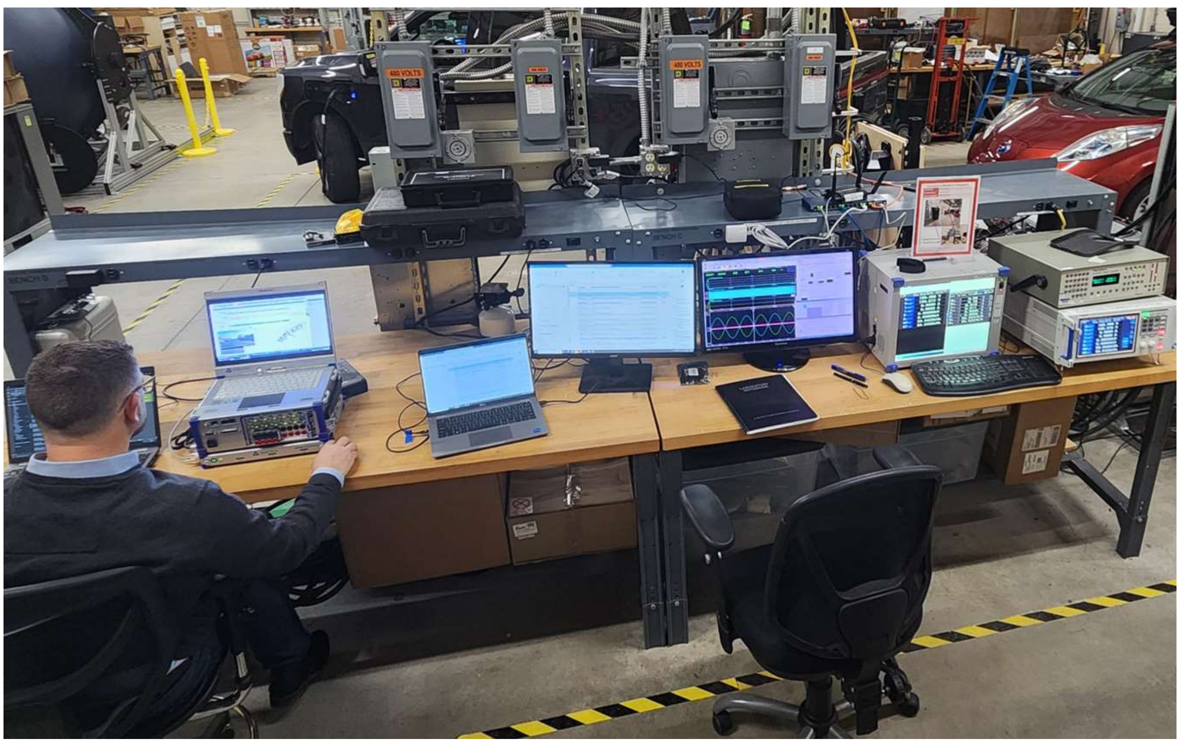
- Accuracy requirements.

The industry may also benefit from additional testing of the energy measurement capabilities of EV telematics systems in support of standards development related to items such as:

- Charging at temperature extremes.
- Charging of an aged battery.
- More exploration of auxiliary load impacts.
- Measurements when power export from a vehicle is involved (vehicle to load, home, or grid).
- Testing of more vehicle brands and models.

APPENDIX A: TEST PROTOCOL

Test Protocol for Measurement Accuracy of EV Charging Telematic Systems



A Recommend Practice by EPRI

September 2024

1. Scope

The intent of this document is to develop a recommend practice for assessing the energy measurement accuracy of telematic systems for electric vehicle charging, as they are presented today. Additionally, this document addresses the conditions, instruments, and methods for obtaining reliable measurements for EV charging data for comparing to telematics.

The telematics data collection source (the voltage and current sensors in the EV) could be located at any point in the EV charging system. The standard-reference measurement is being collected at a point upstream of these sensors, so there will be some energy loss and/or utilization between these measurement points. Therefore, if data is available local to the EV, it should be compared to the telematics data and determined if there's any inherent error related to the telematics system itself.

For consideration of evaluation, the system boundary is established in Figure A-1. This boundary will define the testing elements and measurement points for testing purposes deemed to be expected for normal uses. The System Under Test (SUT) includes the EVSE, EV, and an EV Telematics System. A NIST traceable calibrated reference meter is the standard for measuring the total load of the charging EV and the power consumption of the EVSE controlling the charge. In addition, an optional reference meter could be added downstream of the EVSE for load and loss comparison closer to the charge port of the EVSE.

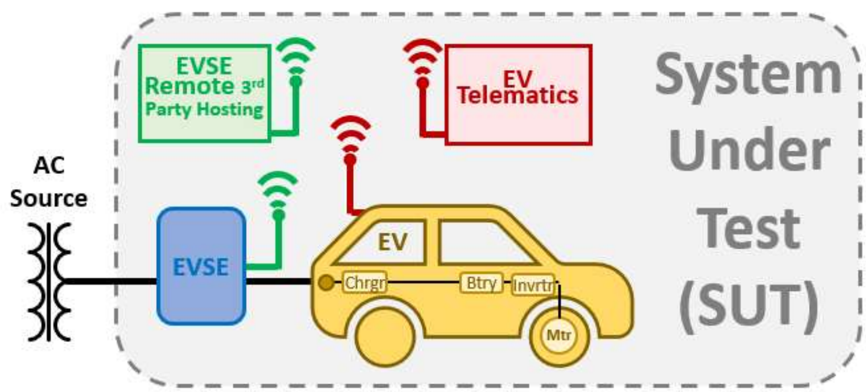


Figure A-1
System Boundaries

2. References

2.1. Applicable Documents

2.1.1. SAE International (formerly The Society of Automotive Engineers) Publications

- SAE J2894/2 & J2894/2
- Provides guidance on power quality requirements and test procedures if needed.

2.1.2. IEEE (Institute of Electrical and Electronics Engineers) Publications

- IEEE 1159-2019
- IEEE 519-2014
- Provides guidance on power quality limits during testing.

2.1.3. NIST (National Institute of Standards and Technology) Publications

- NIST Handbook 44
- Guidance on EVSE measurements.

2.1.4. NEC (National Electric Code 2023)

- Overall guidance for safely installing electrical wiring and equipment.

3. Definitions

3.1. Definitions listed for reference

3.1.1. EV (Electric Vehicle): A vehicle that is propelled by one or more electric motors, using energy stored in rechargeable batteries.

3.1.2. EVSE (Electric Vehicle Supply Equipment): The hardware and associated equipment that delivers energy to recharge electric vehicles (EV's).

3.1.3. Telematics: The integrated use of telecommunications and informatics for sending, receiving, and storing information relating to remote EV's and the EVSE's used.

3.1.4. PCC (Point of Common Coupling), which represents the utility access point for measurement. This location is just upstream relative to the EVSE.

3.1.5. SoC (State of Charge): is the current level of charge in a rechargeable battery expressed as a percentage of its total capacity.

3.1.6. ΔSoC%: Total SoC between the start of charging (SoC^{Start}) and the end of charging (SoC^{End}). Note, in order to be a true integer measurement, the start and end must coincide with the vehicle display change as illustrated in Figure A-2 below.

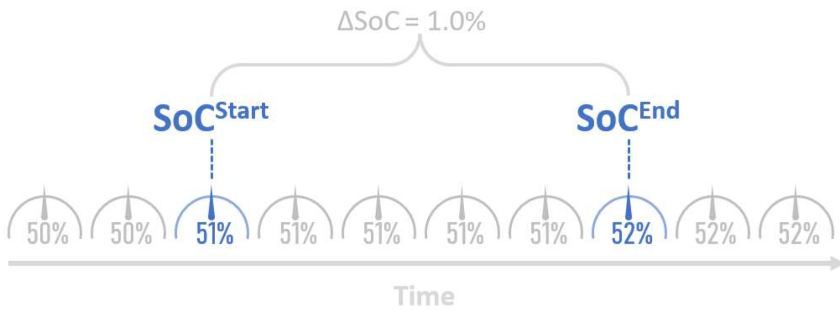


Figure A-2
ΔSoC% is the Total SoC between the start of charging (SoC^{Start}) and the end of charging (SoC^{End})

3.1.7. OBD: (On Board Diagnostic) port (II) are typically standard on vehicles and via CAN bus protocol may allow measurement of otherwise unreported vehicle data and diagnostics.

3.2. Equations

3.2.1. Percent Difference

This protocol understands that direct access to the EV measurement location is not accessible to capture a common measurement for comparison to the standard measurement reference; instead, the standard measurement is located at a more accessible location that is located upstream of the EV and EVSE. Because of this we cannot refer to comparison calculation in common terms as "percent error"; instead, this comparison will be calculated and referred to as a "percent difference" instead. The following equation will be used for reporting percent difference.

$$\%Diff = \frac{(Reported\ Value - Reference\ Value)}{Reference\ Value} * 100$$

3.2.2. Percent SoC to Energy (Wh)

If the EV displays SoC data without charging energy (Wh) data, then the following equation can be used to estimate the amount of charging energy used during a charge session. Note that the start of the standard measurement must coincide with the increment of the SoC^{Start} value. Also note that most telematic systems start their charge session when the vehicles charge cable is plugged in, so prior to starting a standard measurement, a separate charging session (plug and unplug) may be needed to position the SoC at the increment position.

$$Wh = (\%\ SoC^{End} - \%\ SoC^{Start}) \times (Utilized\ Battery\ Size\ in\ Wh)$$

4. Requirements

4.1. Instrumentation

The following instruments may be needed for testing. All testing equipment should be calibrated and NIST traceable. Equipment information should be listed on the data sheet.

- Power Analyzer
  - Primary measurement: Energy in Watt-Hours (Wh), with at least 0.1 Wh resolution
- Power Quality Meter
  - Primary measurement: Clean or defined source of power quality.
    - Distortion
    - Voltage regulation
- Thermometer
- Barometer
- Humidity Meter
- Timer and/or stopwatch
- Voltmeter
- Programmable Power Source

4.2. Test Setup

This section provides a guide for properly setting up test equipment for measurement accuracy testing as illustrated in Figure A-3. A means of quick disconnect from all energy sources should be readily available to the operator and conspicuously posted for others. EVSE equipment should be connected downstream of the grid simulator with appropriately sized wire and circuit protection rating based on EVSE manufacturer's provided nameplate values. Properly sized current transformers should be placed at the input power of the EVSE along with voltage probes from the standard reference power analyzer. No other components should be connected inline between the EVSE and reference meter's sensing probes. There are six measurement points listed in the SUT:

4.2.1. M1: Standard Reference Meter that is located at the PCC just upstream of the EVSE and will be compared to all SUT measurements.

4.2.2. M2: Optional Reference Meter that is located at the EV plug/receptacle and is an alternate location to compare all SUT measurements.

4.2.3. Ms: Local EVSE charging measurement data.

4.2.4. Mr: Remote 3rd Party EVSE charging data.

4.2.5. Mv: Vehicle charging measurement data.

4.2.6. Mt: Telematics charging data

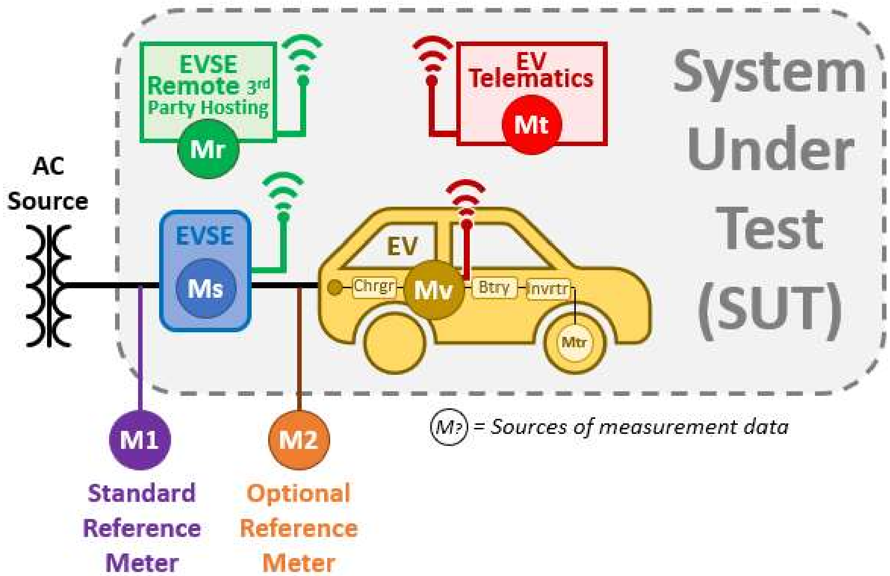


Figure A-3
EVSE Test Setup

4.3. Data Collection

A data collection sheet for each test is shown below in Figure A-4. For each test capture the manufacture information in the designated classified space. To help anonymize manufacturer information, a space has been provided to assign alphanumeric identifiers to each provider—EV#, EVSE (S#), Telematics (T#), and EVSE Remote Host (R#). Each energy charging measurement should be written in watt-hours (Wh) with at least 1 Wh resolution. The percent difference values are derived from the Standard or Optional Reference Meter and each measurement point in the SUT. Optional data collection could include power quality waveform data to assure that the source voltage is clear of any power quality issues that may affect measurements. See IEEE 519 on limits and measurement for harmonic distortion.

When testing a series of EVs and comparing, use the same EVSE. When testing a series of EVSEs and comparing, use the same EV.

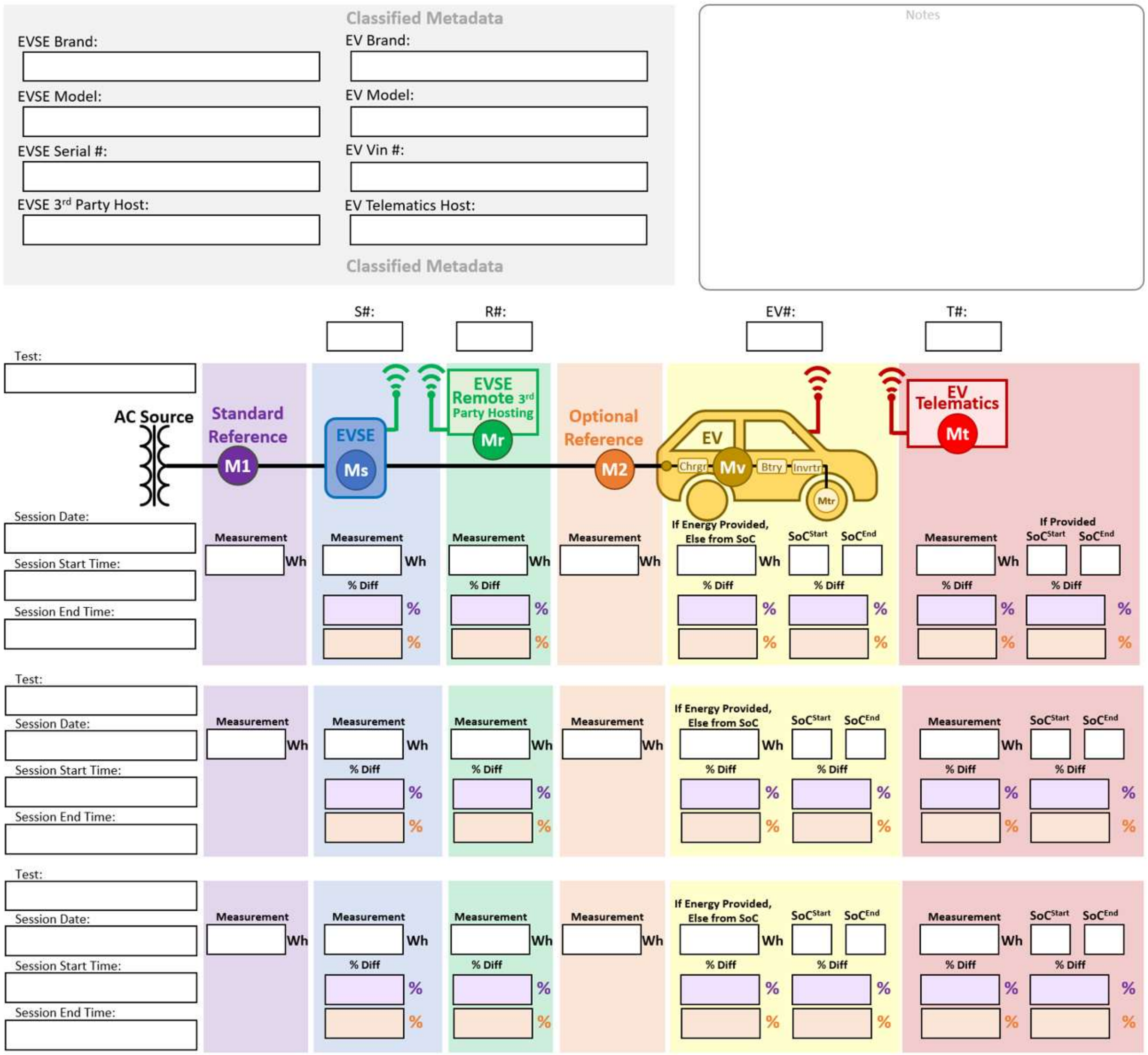


Figure A-4
EVSE Test Data Collection Sheet

4.4. Conditions

4.4.1. Test Duration

Unless directed otherwise, the standard test duration should be either 1-hour or close to 1-hour when obtaining a delta-SoC integer value from the EV. To determine the Delta-SoC% for a one-hour charge divide the EVSE charge rate (for example 7.2 kWh for some L2 EVSE's) by the EV's Usable Battery Capacity (for example 131 kWh). In the example shown below in Figure A-5 the result is a Delta-SoC% of 5.49%; however, most EVs only provide integer values of SoC, so this Delta-SoC% would be rounded to 5%. Note that the start of the standard measurement must coincide with the increment of the SoC^{Start} value from the EV. Also note that most telematic systems start their charge session when the vehicles charge cable is plugged in, so prior to starting a standard measurement, a separate charging session (plug and unplug) may be needed to position the SoC at the incremental position. Be sure to provide the standard delay between charge sessions.

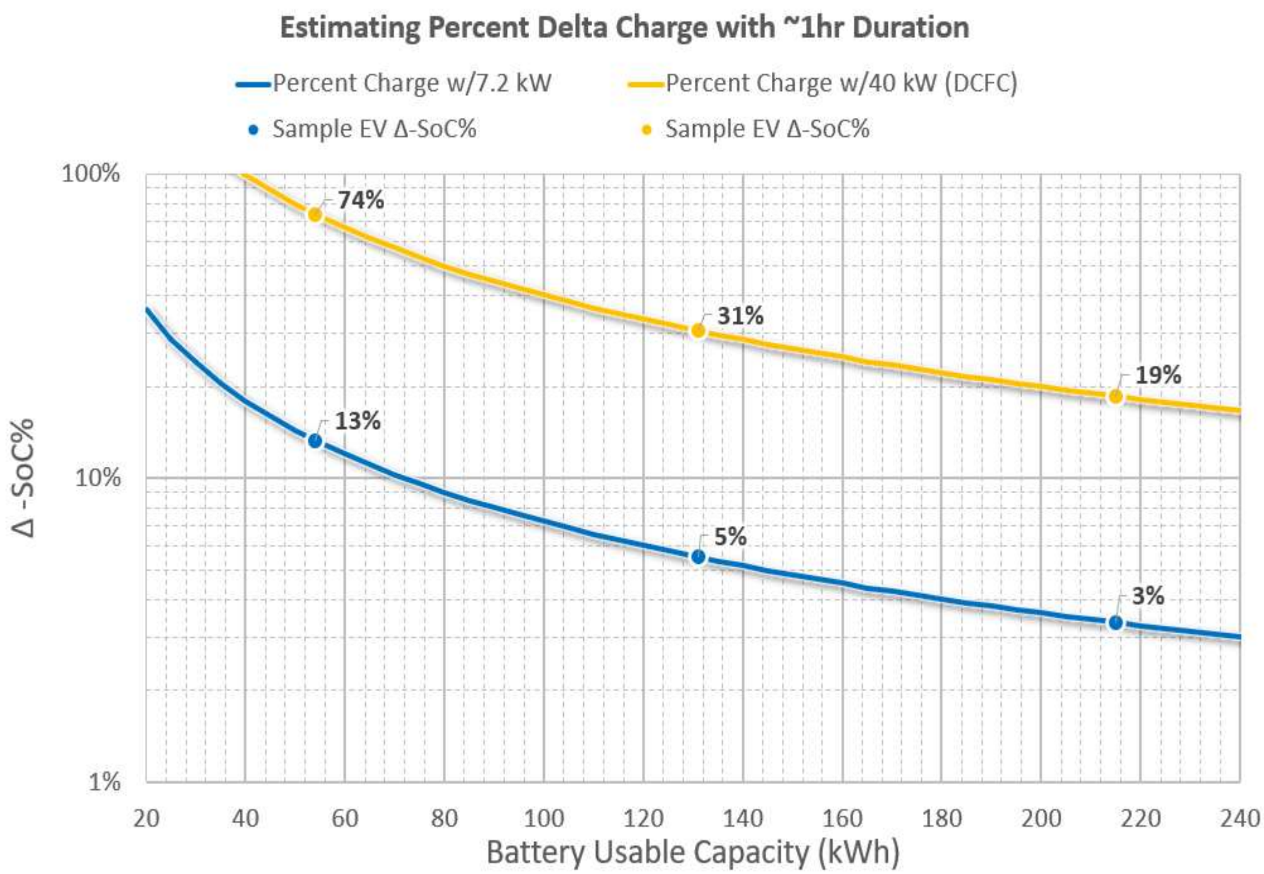


Figure A-5
Battery Change in State of Charge vs. Battery Usable Capacity

4.4.2. Wait period

A wait period between tests should be established. This can be a time period such that enough time has passed that the reporting entities does not combine two back-to-back charging sessions into one. Another approach could be to allow the reporting entities to post the most recent charge session completed before continuing to the next test. This time between charges will ensure that the provider does not combine 2 charge sessions into one. Most testing suggests that 30 minutes is an appropriate period to consider as default.

4.4.3. Ambient Temperature

The ambient temperature should be kept at 25 deg C (+/- 5 deg) for all testing durations unless specific cold/hot tests are being conducted.

4.4.4. Normal conditions

For normal charging conditions, a power source utilizing 240V at 60Hz should be applied to the Level II EVSE unless otherwise stated. Ambient temperature should be established and maintained unless otherwise stated. It is recommended that the EV battery SoC should be <80% when conducting the tests referred to in this document. The EV should be in off mode (no accessories running) unless otherwise needed for testing purposes.

Typically, DCFC tests will require a much larger power source than what is needed for Level II testing. For this instance, it may not be possible to acquire a controllable power source for testing capable of supplying the necessary charging power, typically >30kW. In the case of sourcing the DCFC equipment from the utility grid, it should be that the inherent voltage magnitudes, unbalance, along with the background harmonic levels are adequately understood, measured, and reported. In addition, measuring the secondary of the inverter with an additional reference meter should be considered. Inherent losses in converting AC to DC will likely be of interest.

4.4.5. Electrical Source Power Quality

If available, use a source connection clean of harmonics and a power source with power rating appropriate for maximum load. When grid conditions are not ideal, the use of a programmable power source can provide a harmonic free environment and the necessary voltage control to execute Non-Standard Voltage Tests.

4.4.6. EVSE Installation

It is recommended to follow NEC 2023 guidelines for conductor size and circuit protection when wiring EVSE. Keeping short lead lengths <10' from the source to the EVSE input terminals is preferred. EVSE should be near a strong source of WiFi or hard-wired internet connection depending on the EVSE.

5. Test Methods

For the following test methods, only test 5.1.1 and test 5.1.6 are required to be repeated three times for precision. The other test are strictly to determine if the test method creates a significant error greater than the basic test.

5.1.1. EV Basic ΔSoC Charging Test

- Be sure the EV is previously charged to an SoC^{Start} position as described in 3.1.6.
- Duration is based on an integer Δ-SoC% charge that last for approximately ~1-hour based on method in 4.4.1 and the SoC to energy equation in 3.2.2.
- After each charge session give a 30-minute delay between subsequent charge sessions.
- Repeat this test three times to test precision of accuracy measurements.

5.1.2. Charge with Auxiliary Load – Net Positive

- Adjust an auxiliary load such as heating or air-conditioning and the EV Charge level for Net Positive Charge (Aux Load < Charge Rate / 1.5).
- The duration for this charge is 1-hour with a 30-minute delay between subsequent charge sessions.

5.1.3. Charge with Auxiliary Load – Net Negative

- Adjust an auxiliary load such as heating or air-conditioning and the EV Charge level for Net Negative Charge (Aux Load > Charge Rate / 1.5).
- The duration for this charge is 1-hour with a 30-minute delay between subsequent charge sessions.

5.1.4. Full Charge with Auxiliary Load

- Turn all auxiliary loads off. Bring EV to full charge. Wait 30 minutes.
- Start test measurements and plug in EVSE under test. EV may charge a small amount.
- Wait for EV to command EVSE to state B (disengages EVSE relay).
- Wait 5 minutes, and then engage auxiliary load for remaining duration of test that totals 1 hour from the start.
- 30-minute delay between subsequent charge sessions.

5.1.5. Short Term Charge Test

- Conduct a total of three 5-minute charge sessions with a 1-minute delay between subsequent charge sessions. Total duration should be 17 minutes. Make note of each standard measurement after each 5-minute charge.

5.1.6. EVSE Basic Charging Test

- Conduct a 1-hour test of charging with a 30-minute delay between subsequent charge sessions.
- Repeat this test three times to test precision of accuracy measurements.

6. Safety Procedures and Abnormal Conditions

6.1. Unexpected heating of charging components

6.1.1. If it is observed that a charging conductor cable/wire or charging handle (J1772) is warm to the touch, this condition should be reported immediately, documented in the lab notebook, and further investigated as to the root cause of the heating (loose connection, etc.). Heated components under any charging condition are not part of this testing procedure unless otherwise stated. Due to understood power efficiency implications and inaccurate measurements the abnormal condition needs to be further understood and quantified before resuming testing.

6.2. Unexpected EV or EVSE behavior

6.2.1. If a fundamentally unexpected behavior is observed at any point for the EV or EVSE e.g., EV not charging when plugged in, stop testing and assess.

APPENDIX B: EPRI PROJECT TEAM & CALIBRATION CERTIFICATES

EPRI Project Team

- Thomas Cooke, Project Manager
- John Halliwell, Project & Technical Advisor
- Letitia Midmore, Project Advisor
- Ben Clarin, Technical Advisor
- Viswanath Ananth, Technical Advisor
- Jason Johns, Test and Measurement Lead Engineer
- Peyton Sizemore, Test and Measurement Advisor

Calibration Certificates for Measurement Standards M1 and M2

Trescal

Trescal
108 ENTERPRISE DR ELIZABETH CITY, NC 27909-6340
Trescal.us

Calibration Certificate

Certificate #: US011-MCL-CI-24021323	**Client ID:** 100004933	**Customer:** ELECTRIC POWER RESEARCH COMPANY INC. [5045]
Ref Procedure: Hioki PW6001 Calibration Manual	**Brand:** HIOKI	**Contact:** JONATHAN MORRELL
Date: 01/19/2024	**Model #:** PW6001	**Address:** 942 CORRIDOR PARK BLVD.
Interval: 12 Months	**Serial #:** 170534958	Knoxville, TN 37932
Due Date: 01/31/2025	**Range:** N/A	**Location:** LAB
Technician: Tim Goetz	**Description:** ANALYZER, POWER QUALITY	**Room:** N/A
Client Ref: 4700011233		

Environmental Conditions

Ambient Temperature: 22 ° C
Barometric Pressure: N/A
Ambient Humidity: 30 % RH
Standard Barometric Reference for Density Conversions

As Received	As Returned	Action Taken
In Tolerance ☑	In Tolerance ☑	Full Calibration ☑

Comments

Standards Used

Description	Brand	Model #	Serial #	Due Date	NIST Traceability #
CALIBRATOR	FLUKE	5500A	7835024	11/30/2024	NCL-35024
DIGITAL MULTIMETER	HEWLETT PACKARD	3458A	2823A19852	03/14/2024	MCL3-19852

Digitally signed by Tim Goetz
Date: 19Jan2024 03:43:05
Reason: I created this document.

Authorized Signature

Trescal

Trescal
108 ENTERPRISE DR ELIZABETH CITY, NC 27909-6340

Trescal.us

Calibration Certificate

Certificate #:	US011-MCL-CI-24021862	**Client ID:**	C001863	**Customer:**	ELECTRIC POWER RESEARCH COMPANY INC. [5045]
Ref Procedure:	Hioki PW3390	**Brand:**	HIOKI	**Contact:**	JONATHAN MORRELL
Date:	01/21/2024	**Model #:**	PW3390	**Address:**	942 CORRIDOR PARK BLVD.
Interval:	12 Months	**Serial #:**	190234086		Knoxville, TN 37932
Due Date:	01/31/2025	**Range:**	N/A	**Location:**	LAB
Technician:	Tim Goetz	**Description:**	METER, POWER	**Room:**	N/A
Client Ref:	4700011233				

Environmental Conditions

Ambient Temperature: 19 ° C
Barometric Pressure: N/A
Ambient Humidity: 39 % RH
Standard Barometric Reference for Density Conversions

As Received	As Returned	Action Taken
In Tolerance ☑	In Tolerance ☑	Full Calibration ☑

Comments

Standards Used

Description	Brand	Model #	Serial #	Due Date	NIST Traceability #
CALIBRATOR	FLUKE	5500A	7835024	11/30/2024	NCL-35024
DIGITAL MULTIMETER	HEWLETT PACKARD	3458A	2823A19852	03/14/2024	MCL3-19852

Digitally signed by Tim Goetz
Date: 21Jan2024 12:40:05
Reason: I created this document.

Authorized Signature

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PROGRAM
Electric Transportation, P18

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3002031024 **September 2024**

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