Appendix 10 Generic EVSE Efficiency Test Procedure

10.1 Test methodology

Electric Vehicle Supply Equipment (EVSE) charge cycle efficiency is directly determined through the relationship between the input and output power over the 0-100% range of the maximum rated output power of the EVSE under test.

The ratio of the EVSE's output to input power (efficiency) over the 0-100% output power range yields an efficiency curve which can be used to provide an efficiency value for any given output power level.

Total EVSE energy output relative to energy input over a full change cycle yields a single efficiency figure for the EVSE *in conjunction with the particular EV tested*. It should be noted that this value could vary significantly for the same EVSE with different EVs, or even EVs of the same model at different temperatures (i.e. internal thermal management) or battery state-of-health (SOH) due to varying load profiles they will request of the EVSE.

10.1.1 Outcomes

- Efficiency curve of the EVSE under test.
- Overall efficiency value of charger using a representative EV.

10.1.2 Additional outcomes

- Generalised efficiency of the EVSE under test in 'real world' deployment within a representative EV fleet if many EV models are tested.

10.1.3 Equipment

The test equipment chosen to monitor the input and the output power must be capable of measuring the full ranges of voltages and currents expected on both the AC input and AC or DC output sides of the EVSE (depending on the nature of the EVSE under test), and at an accuracy level in excess of that required for the testing.

In practice, this can be achieved by a number of means, but the easiest is typically a specialist power measurement device, which can usually also provide additional measurements of power quality. Inductive current measurement devices provide easy current measurements, but careful consideration of their thermal performance and overall accuracy must be made.

Voltage and current measurement error specifications should be considering in percentage form. Total measurement accuracy is then simply the sum of the combination of the percentage errors. Thus, the input voltage error added to the input current error will provide the input power error, and similarly for output voltage and current. The addition of both the input and output power errors will provide the overall efficiency error.

10.1.4 Equipment configuration

10.1.4.1 Best practice

In order to ensure the most accurate measurements of efficiency, the synchronisation of the input and output power measurements is vital. Should one measurement set be delayed relative to the other, the efficiency curves will be distorted because the charge power varies over the charge cycle.

Equally, the measurement of the input and output power will be impacted by resistive losses (and hence voltage drops) within the AC power feed cable and AC or DC output cable. Measurement of voltages at the terminals within the EVSE will eliminate these variables, simplifying the analysis.

Thus:

- Input and output power are recorded on the same device. This requires voltage and current measurement of 1-3 AC input phases plus the voltage and current measurement of the 1-3 AC output phases or DC output.
- Input voltage measurement should be taken at the main input terminals to the EVSE, which will require termination within the EVSE.
- Output voltage measurement should be taken at the output terminals within the EVSE, which again will require termination within the EVSE.

10.1.4.2 Acceptable alternatives

It is often difficult to acquire all the input and output power measurements on the same device due to the number of measurement channels required on the recorder. Should two or more measurement devices be required, it is vital that all devices are synchronised both at the commencement of the test cycle, and throughout the cycle. Failure to achieve this may result in one or more measurements leading or lagging the others, distorting the results.

Its is also often difficult to terminate voltage measurement points within the EVSE. Should this not be possible, the resistances of each conductor between the EVSE and the voltage measurement point must be accurately measured. Generally, a multimeter is insufficiently accurate, and a high-accuracy micro-Ohm meter should be employed to acquire these measurements.

For a 3-phase AC input EVSE, the input power measurement compensation equation is given below, where '$R_{Input\ cable}$' is the resistance of an individual conductor, assuming all conductors have the same resistance.

$$P_{IN\ actual} = P_{IN\ measured} - R_{Input\ cable}\left({I_{IN\ measured\ P1}}^{2} + {I_{IN\ measured\ P2}}^{2} + {I_{IN\ measured\ P3}}^{2}\right)$$

For a single-phase AC input EVSE the input power measurement compensation equation is given below, where '$R_{Input\ cable}$' is the resistance of an individual conductor, assuming all conductors have the same resistance.

$$P_{IN\ actual} = P_{IN\ measured} - \left({I_{IN\ measured}}^{2} \times 2 \times R_{Input\ cable}\right)$$

For a 3-phase AC output EVSE, the output power measurement compensation equation is given below, where '$R_{Output\ cable}$' is the resistance of an individual conductor, assuming all conductors have the same resistance.

$$\begin{aligned} P_{OUT\ actual} = {} & P_{OUT\ measured} \\ & + R_{Output\ cable}\left({I_{OUT\ measured\ P1}}^{2} + {I_{OUT\ measured\ P2}}^{2} + {I_{OUT\ measured\ P3}}^{2}\right) \end{aligned}$$

For a single-phase AC output EVSE or a DC output EVSE, the output power measurement compensation equation is given below, where '$R_{Output\ cable}$' is the resistance of an individual conductor, assuming all conductors have the same resistance.

$$P_{OUT\ actual} = P_{OUT\ measured} + \left({I_{OUT\ measured}}^{2} \times 2 \times R_{Output\ cable}\right)$$

Note: Some EVSEs may have a three-phase input and depending on the EV under test, only supply the vehicle with single-phase charging.

Note: Measurement of the voltages remote from the EVSE terminals will effectively result in a higher measured input power and lower measure output power if the cable resistances are not considered.

Thus:

- If using two or more measurement devices to gain the necessary number of measurement channels, all devices must have compatible synchronisation facilities and be kept in time synchronisation over the entire test cycle.
- If required to measure the input and/or output voltages remote from the EVSE terminals, the cable resistances between the EVSE and the measurement points must be measured and compensated for.

10.1.5 DC EVSE test methodology

To capture the charge profile, an EV is used to provide a load. The EV chosen must present to the charger a load profile that ensures the EVSE is subjected to loads from 0-100% of its rated output. Not all EV's will accept the maximum power offering of all EVSEs so careful consideration should be made to match the chosen EV to the EVSE.

Of particular note is the battery voltage of the test EV. Experience has shown that many EVSE manufacturers appear to specify a maximum power output that can only be achieved at voltages in excess of the maximum battery voltage of common EVs.

The test EV is moved to the EVSE location, and the monitoring equipment configured for recording the charging data as per Figure 10.1. Initial conditions are a fully discharged battery (as permitted by the internal vehicle BMS) and the EV (and its battery) at ambient conditions.

The charging cycle is commenced and at charge completion, the data is stored for analysis. During this process the vehicle must be continuously monitored for any faults or issues and supervised to ensure the safety of those in the vicinity of the testing.

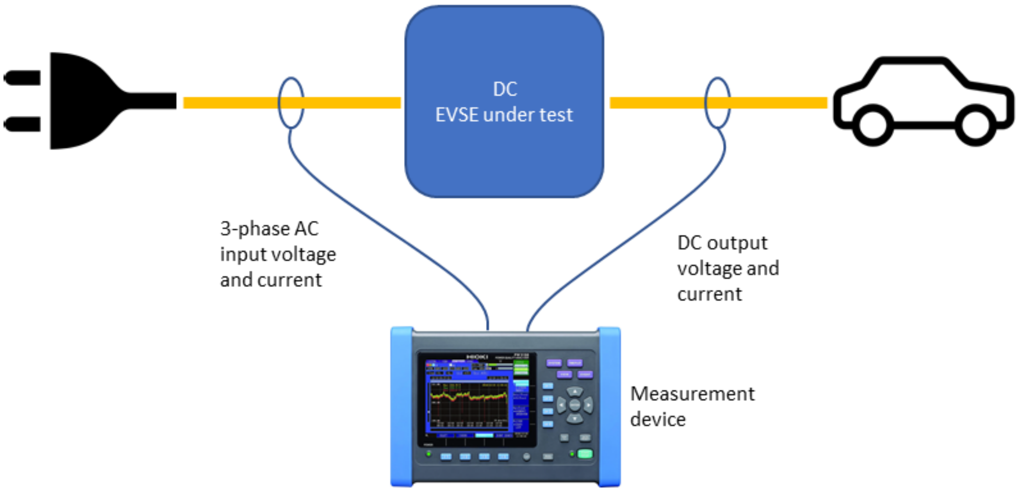

Figure 10.1: DC charge point monitoring configuration.

10.1.6 AC EVSE test methodology

Testing an AC-output EVSE is more challenging due to the effects of the internal AC-DC converter/charger within EVs. A typical internal EV charger tends to present a static load to the EVSE, which greatly reduces the range of loads measured, limiting the resolution of the resulting data when extracting efficiency curves.

AC-output EVSEs can be more accurately tested across a wide range of loads with a controllable resistive single/three-phase dummy load in place of the vehicle for both single and three-phase configurations as per Figure 10.2. This method also avoids the impact of the vehicle's internal charger from any power quality measurements of the EVSE should they be required.

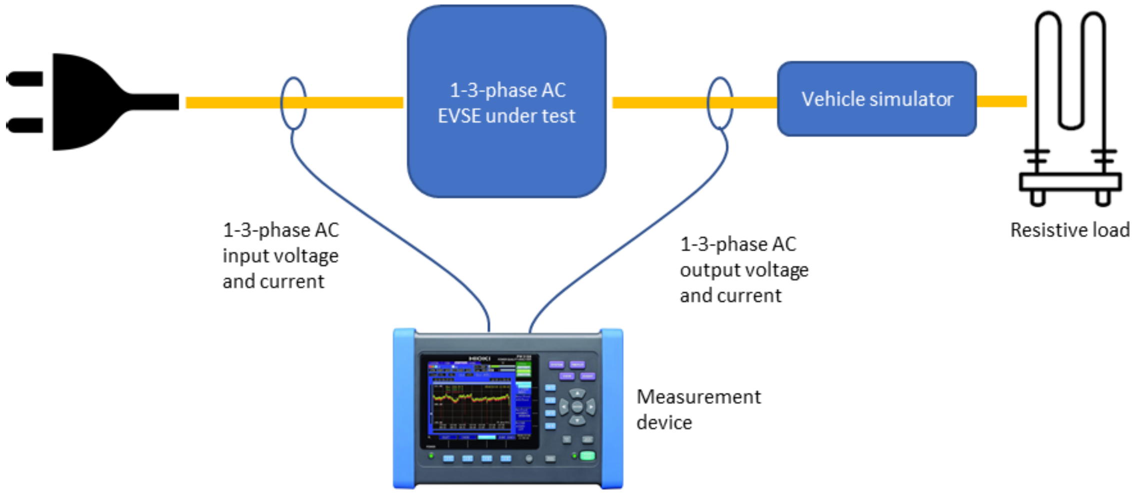

Figure 10.2: Single-phase AC charge point monitoring configuration with 'ideal' load.

The 'vehicle simulator' shown in Figure 10.2 can be constructed following the circuit shown in Figure 10.3. Electrical safety must be considered and qualified personnel used to construct and operate such equipment.

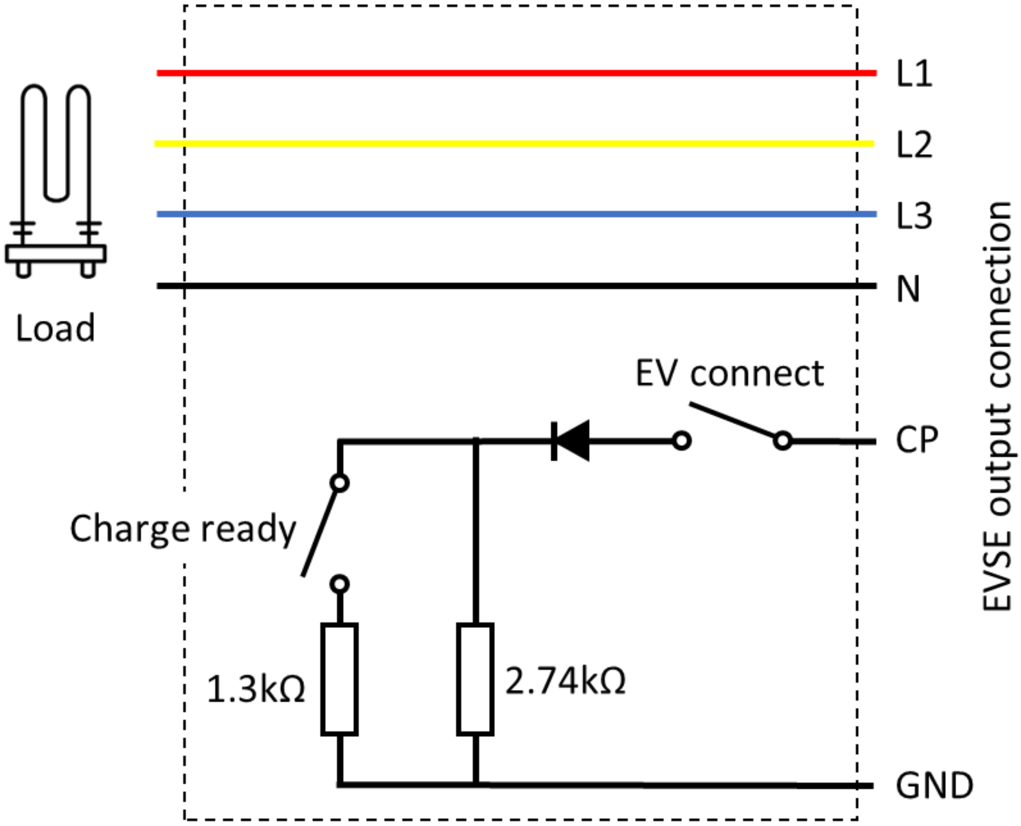

Figure 10.3: EV emulator circuit.

To perform the test, the monitoring equipment configured for recording the charging data as per Figure 10.2.

A charging cycle is commenced on the EVSE and the ‘EV connect’ switch is closed, followed by the ‘Charge ready’ switch on the EV simulator (Figure 10.3). The load is then varied from 0-100% of the rated power of the EVSE, then the charge terminated by opening the ‘Charge ready’ switch, followed by the ‘EV connect’ switch on the EV simulator. The measurement data is then stored for analysis. During this process the test must be continuously monitored for any faults or issues and supervised to ensure the safety of those in the vicinity of the testing.

10.2 Results

At the termination of the test cycle, the dataset is manipulated to provide a table with columns representing the input power (considering and compensating for any resistive losses in the measurements if applicable) and output power (again considering and compensating for any resistive losses in the measurements if applicable). These columns can then be used to generate an efficiency column from

$$Efficiency = \frac{P_{OUT\ measured}}{P_{IN\ measured}}$$

The efficiency column can then be used in a scatter plot against input power to achieve an efficiency curve for the EVSE from 0-100% rated output power.

Verify that the power rating achieves the maximum rated power of the EVSE.

Error curves can be added that add and subtract the total measurement uncertainty from the efficiency curve.

10.3 Considerations for ‘real world’ efficiency estimates

Whilst this test procedure will realise an efficiency curve for a given EVSE, each EV has a specific load profile under charge, that can also vary according to parameters such as battery temperature or state-of-health.

For example, should any EV predominantly consume power at a level where the tested EVSE is less efficient, the overall efficiency of the EVSE in that environment is lower. This could occur, for example, for a DC EVSE where a high voltage capable EVSE is used with a lower battery voltage EV.

A total efficiency value for the EVSE in conjunction with a given EV can be obtained by the ratio of the total energy supplied to the EV relative to the total energy consumed by the EVSE.

Should a ‘real world’ efficiency metric be required for the EVSE, a representative range of EVs can be tested and the results used in average form, or even apportioned according to the dominance of each EV type within the overall EV fleet.

Appendix 11 Generic EVSE OCPP Test Procedure

11.1 Test methodology

In order for the network load demanded by the Electric Vehicle Supply Equipment (EVSE) infrastructure to be visible and controllable by network operators, a form of remote management must be implemented. The Open Charge Alliance (OCA), a consortium of over 200 EVSE manufacturers and parties with interests in EVSE infrastructure, has developed the Open Charge Point Protocol (OCPP). This is an open, and currently the best supported, standard used for EVSE infrastructure management. Version 1.6 (OCPP 1.6) is the most commonly implemented by EVSE manufacturers, despite version 2 being mature.

This test procedure is focussed on the 'visible and controllable' aspects of the OCPP 1.6 standard – though the standard provides significantly more functionality, including remote firmware updates, reservation, user access management etc.

EVSE OCPP compliance is tested by confirming the appropriate responses and reported states of the EVSE when interrogated/controlled over the OCPP system.

11.1.1 OCPP test environment

11.1.1.1 Best practice

The Open Charge Alliance provides an OCPP Compliance Test Tool version 2 (OCTT2) [1]. This is a commercially purchasable software package that automates the test protocol, and provides a compliance report. Following the documentation provided by the OCA will provide a comprehensive test report.

Note that this test tool will not specifically test reported power consumption to measured power consumption, nor the accuracy of implemented power levels during smart charging. These tests must be performed in addition to, or in conjunction with, using the OCTT2.

11.1.1.2 Acceptable alternative

The OCTT2 software is relatively expensive. Alternative open-source software packages that implement the OCPP services are available that can be used to manually test much of the OCPP functionality.

A relatively capable implementation for an OCPP backend server is the open source and GPL licenced package titled 'SteVe'. From the developer's description;

> *SteVe started its life at the RWTH Aachen University in 2013. The name is derived from Steckdosenverwaltung in German (in English: socket administration). The aim of SteVe is to support the deployment and popularity of electric mobility, so it is easy to install and to use. It provides basic functions for the administration of charge points, user data, and RFID cards for user authentication and was tested successfully in operation* [2].

SteVe does not, however, support use of any security profiles, so all applicable functionality of the EVSE under test must be configured to operate with security settings disabled. Some EVSE may demand basic security which blocks access by SteVe, such as HTTP Basic Auth. Basic Auth can be provided by an intermediary service, such as a proxy installed on an Apache 2 web server that acts as an intermediary to inject the required security.

11.1.2 Test configuration

If using the SteVe backend OCPP server, this is connected to the EVSE under test through a wired Ethernet link through a network switch. Alternative OCPP backend servers, or the OCTT2 tool should be configured and connected in accordance to the providers instruction.

The EVSE is then connected to a vehicle simulator and resistive load in the case of AC EVSEs, or to a vehicle for DC EVSEs.

The configuration of the test environment is shown in Figure 11.1. Power measurement of the EVSE input power is required to confirm that the reported power consumption over OCPP matches the actual power consumption of the EVSE. The oscilloscope is required to verify that the EVSE is correctly signalling the desired power level to the EV. This should be connected to the Control Pilot (CP) line within the vehicle simulator (Figure 10.3).

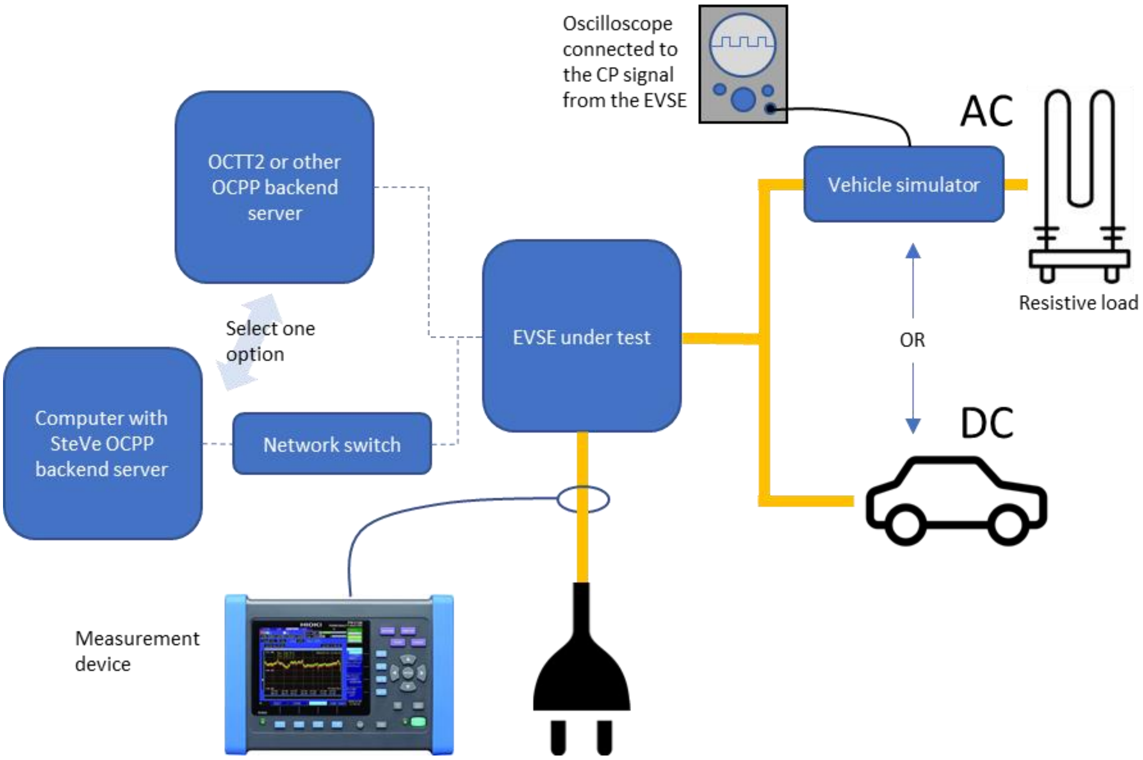

Figure 11.1: OCPP test environment configuration.

In both AC and DC test cases, the load (resistive or vehicular) must be sufficiently large to ensure that the full rated EVSE output power can be achieved.

Note that for the DC test case, not all EV's will accept the maximum power offering of all EVSEs so careful consideration should be made to match the chosen EV to the EVSE. Of particular note is the battery voltage of the test EV. Experience has shown that many EVSE manufacturers appear to specify a maximum power output that can only be achieved at voltages in excess of the maximum battery voltage of common EVs.

For the AC test case, the load must be manually adjusted in accordance with the signalling on the Control Pilot (CP) line.

11.2 OCPP tests

Two key tests are required to ensure the 'visible and controllable' aspects of the OCPP 1.6 standard are functional for each EVSE.

1. Ensure that the power demand from the network is correctly reported by the EVSE.
2. Ensure installed smart charging profiles are correctly implemented.

These tests can be run concurrently, with the smart charging steps used to generate a range of configured power levels at which the EVSE will report power consumption that can be directly compared to power demand measured directly with a power meter.

In addition, to gain a better overall understanding of an EVSEs general compliance to the OCPP standard, a subset of the *OCPP Certification Program Document 2, "Test Procedure & Test Plans"* [3], can tested. It should be noted that exhaustive testing of OCPP is time consuming, especially testing boundary conditions.

A pragmatic selection of test components taken from the certification program that could be tested tested are;

- Remote actions Happy flow[1]
- Resetting Happy flow
- Unlocking Happy flow
- Configuration Happy flow
- Basic Actions Non-happy flow
- Remote Actions Non-Happy Flow
- Unlocking Non-happy flow
- Power Failure Non-Happy Flow
- Offline behaviour Non-Happy Flow
- Configuration Keys Non-Happy Flow

11.2.1.1 DC EVSE power consumption reporting accuracy and smart charging performance

The EVSE should have a smart charging profile loaded that steps through the power output range of the EVSE. Multiple steps will ensure good granularity of data. Note that some EVSE will only accept smart charge profile power limits in power units, current units, and some will accept both. Note also that there is significant variation in smart charging capability between EVSEs, with varying limits on the number of steps each EVSE will implement. Should the desired granularity of power output levels exceed the number of steps permitted by the EVSE in a single smart charging session, multiple sessions may be required.

With the smart charging profile installed, the power measurement device should be configured to record, and the smart charging session commenced. Throughout the charge process, the 'MeterValues' status output of the EVSE should be logged. At the termination of the smart charging session, the reported and measured power levels can be used to determine a curve of error (deviation) against the EVSE power input level.

---

[1] The term 'happy flow' and 'unhappy flow' refer to the certification program's nomenclature for 'expected' and 'deviant' behaviour.

Correct implementation of the smart charging profile can be confirmed through the comparison of the desired profile to the recorded profile.

11.2.1.2 AC EVSE power consumption reporting accuracy and smart charging performance

The EVSE should have a smart charging profile loaded that steps through the power output range of the EVSE. Multiple steps will ensure good granularity of data. Note that some EVSE will only accept smart charge profile power limits in power units, current units, and some will accept both. Note also that there is significant variation in smart charging capability between EVSEs, with varying limits on the number of steps each EVSE will implement. Should the desired granularity of power output levels exceed the number of steps permitted by the EVSE in a single smart charging session, multiple sessions may be required.

With the smart charging profile installed, the power measurement device should be configured to record, along with the oscilloscope that is capturing the CP signal. The smart charging session can then be commenced. During the smart charging session, the resistive load must be manually varied according to the CP pulse width ratio. This entails observation of the pulse width ratio on the oscilloscope and adjusting the load as per Table 11.1.

Table 11.1: Control Pilot (CP) state table.

PWM ratio	Target load current
50%	30A
40%	24A
30%	18A
25%	15A
16%	9.6A
10%	6A

During the smart charging session, the 'MeterValues' status output of the EVSE should be logged. At the termination of the smart charging session, the reported and measured power levels can be used to determine a curve of error (deviation) against the EVSE power input level.

Correct implementation of the smart charging profile can be confirmed through the comparison of the desired profile to the recorded CP pulse width ratio captured on the oscilloscope. Note that an AC EVSE does not itself manage the power levels, and success in this test only depends on the recorded CP pulse width ratio against the target power levels, and not the measured or reported power levels.

11.2.1.3 General compliance testing

General compliance testing of all, or a required subset of the OCPP functionality, is performed in accordance with the Open Charge Alliance OCPP Test Protocol entitled *OCPP Certification Program Document 2, "Test Procedure & Test Plans"* [3].

11.3 Considerations

Exhausting testing against the OCPP standard represents a significant body of work that requires an in-depth understanding of the protocol, and is beyond the scope of this guide. In addition, verification of fault reporting will not be possible unless the EVSE actually develops a fault condition. This guideline attempts to outline a generalised process that will provide a degree of confidence that the EVSE under test will correctly report the power consumption over a range of power levels and be capable of managing the provided power level to the EVSE from a remote management point.

The OCPP standard is continuously evolving, and at the time of writing, despite OCPP2.0 offering considerable improvements, especially around security, OCPP1.6 remains the dominant supported version.

This guideline does not attempt to cover all aspects of OCPP compliance, and entirely bypasses the security aspects of OCPP.

References

1. Open Charge Alliance. *OCPP Compliance Test Tool 2*. 2023 20-06-2023]; Available from: https://www.openchargealliance.org/protocols/test-tool-ocpp-201/.
2. Gökay, S. *SteVe*. 2022 [cited 2022 July 12]; Available from: https://github.com/steve-community/steve.
3. Open Charge Alliance, *OCPP Certification Program Document 2, “Test Procedure & Test Plans” V1.0*. 2019.