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EVSE Characterization: V2G EVSE Comparison

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V2G EVSE Comparison

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Disclaimer

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List of Acronyms

AC	alternating current
DC	direct current
EV	electric vehicle
EVSE	electric vehicle supply equipment
kW	kilowatt
THD	total harmonic distortion
V	Volts
V2G	vehicle-to-grid

Executive Summary

As part of the U.S. Department of Energy EVs@Scale consortium Next-Generation Profiles project, results and analysis from the characterization of high-power conductive and wireless charging infrastructure are presented. This characterization is conducted over a wide range of direct current (DC) current and DC voltage operation for nominal test conditions and off-nominal test conditions. Test plans and procedures were developed to define the test configurations and requirements, measurement parameters, and test procedures used throughout testing.

Results from a 2024 study conducted on electric vehicle supply equipment (EVSE) characterization by the Idaho National Laboratory (INL) include two bi-directional vehicle-to-grid (V2G) capable EVSEs. These EVSE are referred to as V2G-EVSE9 and V2G-EVSE10.

Laboratory testing is conducted at nominal test conditions to characterize the power transfer capabilities, efficiency, power factor, and other power quality metrics of the two DC EVSEs capable of V2G bi-directional power transfer. Results from testing show the performance is consistent for V2G-EVSE9 and V2G-EVSE10 when comparing charging to discharging performance, except for V2G-EVSE10 for power transfer when operating above 70% of the rated DC current. V2G-EVSE10 efficiency is >98% while charging and <91% while discharging at the same operating conditions, near maximum-rated current, at 300VDC. In contrast, V2G-EVSE9 results are consistent for charging and discharging. This EVSE is nearly 96% efficient while charging or discharging when operating over 50% of rated AC power.

V2G EVSE performance is also characterized during off-nominal AC grid conditions involving AC voltage deviation (426 VAC to 518 VAC), AC frequency deviation of ±2% (58.8 Hz to 61.2 Hz), and AC voltage harmonics injection. Many test conditions have little-to-no impact on performance characteristics of the two EVSEs; however, there are a few notable findings with significant power transfer capability impacts. AC voltage harmonics injection resulted in negative impacts on power quality attributes for both EVSEs, but with no impact on power transfer capability. Off-nominal AC voltage and frequency conditions resulted in unstable or lack of power transfer capability for both EVSEs. V2G-EVSE9 is unable to transfer power when AC voltage is ≥300V L-N. V2G-EVSE10 is unable to transfer power when AC frequency deviation exceeds ±0.8%.

V2G energy management system transient response and latency are quantified during laboratory testing. V2G-EVSE9 and V2G-EVSE10 utilize cloud-based V2G energy management systems that command the power transfer level between the EVSE and EV. The latency and response characteristics of the entire systems (web-based user interface, V2G energy management system, cellular communications, and EVSE response) are quantified through laboratory testing for V2G-EVSE9 and V2G-EVSE10. V2G-EVSE9 latency ranges from 0.8 to 1.8 seconds, whereas V2G-EVSE10 latency ranges from 3.4 to 8.8 seconds. The ramp rate to a change in power transfer request also differs between the two EVSEs. V2G-EVSE10 ramp rate ranges from 50% to -250% of rated AC power per second, whereas V2G-EVSE9 rate ranges from 95% to -95% of rated AC power per second. At the highest rate of change in power transfer, V2G-EVSE10 can change from full charge power to full discharge power in less than one second.

The V2G EVSE characterization presented in this report provides valuable insights and results for use by numerous entities. This includes modeling and simulation organizations, decision makers, fleet planning, industry stakeholders, and many others involved with the development and deployment of electrified transportation technologies. Additional high-power DC chargers, bi-directional chargers, and inductive power transfer EVSE characterization results are anticipated from additional EVSE brands and models, which will be detailed in future publications in support of the U.S. Department of Energy EVs@Scale consortium Next-Gen Profiles project.

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1 EVSE Characterization Introduction

This report compares measurements and results from two conductive direct current (DC) bi-directional electric vehicle supply equipment (EVSE) characterization studies performed for the U.S. Department of Energy EVs@Scale Next-Gen Profiles project. Both EVSEs are capable of vehicle-to-grid (V2G) operation. Power transfer from the EVSE to an electric vehicle (EV) can charge the EV's battery pack, or reverse power transfer from the EV to the EVSE can provide electrical power to the grid. This report aligns with and supports several other previous reports from this project: EVSE Characterization,[1] EV Profile Capture,[2] Fleet Analysis,[3] and High-Level Analysis and Procedures report.[4]

The characterization of V2G capable bi-directional charging infrastructure provides crucial information for ensuring the reliability, interoperability, and efficiency of the EV charging ecosystem. The thoroughness of this characterization involves the exploration and comparison of production and future charging equipment, which include conductive DC bi-directional EVSE systems. Previous characterization has been conducted and reported on high-power conductive and inductive power transfer EVSEs.[1] Using EVs and EV emulators, the EVSEs can be tested under controlled conditions that are both repeatable and consistent, simulating the diversity of EV characteristics to be expected in production DC charging and discharging operations. Performing these tests in a controlled environment allows for potential issues, optimizations, design improvements, and testing strategies to arise, ultimately fostering a more robust and user-friendly infrastructure for EVs. This paper focuses on the characterization of EVSEs with respect to power and system efficiency at different boundary conditions and focuses less on interoperability and reliability.

This paper's research of V2G-capable bi-directional charging systems characterization is performed using a wide range of DC current and DC voltage charging and discharging conditions to quantify the operational performance of the EVSE. This characterization is conducted at nominal and off-nominal test conditions. V2G bi-directional EVSE characterization aims to explore and compare performance characteristics across boundary conditions pertaining to DC voltage conditions, AC grid conditions, and V2G energy management system request response.

The test article nomenclature in these reports is aligned for cross-report comparison. For example, V2G-EVSE9 refers to EVSE#9 operating with V2G capabilities, including the cloud-based V2G energy management system used to control the charge and discharge power transfer between the EV and EVSE.

1.1 Conductive EVSE Characterization Hardware Configuration

EVSE characterization testing is intended to test an EVSE at a single port. Multi-port/multi-session EVSE operation is not included in the completed characterization. Figure 1 depicts the configuration for EVSE characterization, including the EVSE power cabinets, EVSE dispenser, and an EV emulator that includes a DC load/source. The use of an EV emulator enables repeatable testing across a wide range of voltage test conditions and accelerates testing by alleviating the time required to discharge the battery energy storage system associated with the EV used for EVSE testing. For the EVSE characterization, the EVSE system is considered to be the device under test. The EVSE is not modified out of the standard commercial configuration and settings of the manufacturers. The EVSE is instrumented to capture the metrics detailed in Table 2. The locations of the measurement points are described in subsequent sections.

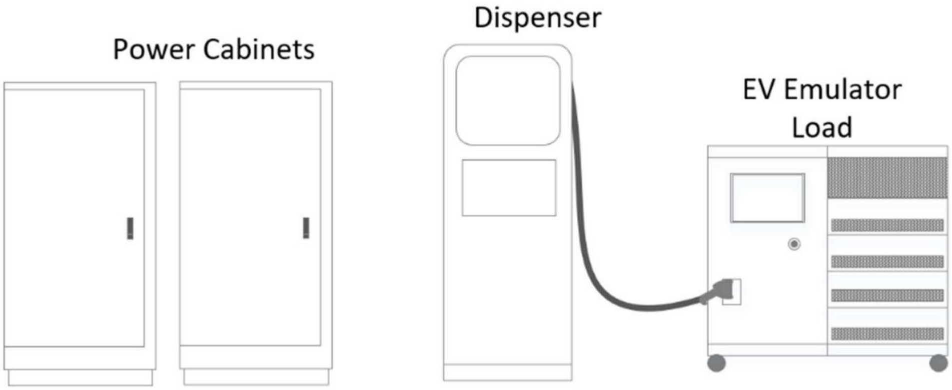

Figure 1. EVSE characterization configuration.

V2G-EVSE10 is comprised of one power cabinet that includes AC-DC power conversion components and one dispenser that includes communications components and one standardized cable for connection to the EV. V2G-EVSE9 is comprised of a single cabinet that includes AC-DC power conversion components, communications components, and one standardized cable for connection to the EV.

Both V2G-EVSE9 and V2G-EVSE10 are capable of power transfer up to the same magnitude as 50 kilowatt (kW)-class DC charging infrastructure. Both V2G EVSEs utilize a cloud-based V2G energy management system that control the power transfer between the EVSE and EV within the power, current, and voltage limitations of both the EVSE and the EV. The V2G energy management systems can operate autonomously using a control strategy based on numerous inputs including price signals, vehicle departure requirements, and site grid loading conditions. The system can also be manually controlled by a fleet owner/operator via a web-based user interface using scheduled power transfer values and durations. For the characterization conducted for these two V2G-capable EVSEs, the manual functionality is used to repeatably control each EVSE per the required test procedures.

Both V2G EVSEs are installed in a laboratory setting as a temporary installation on metal support structures to support the EVSE enclosure size and mass and to enable the installation of the necessary wiring without modifying the concrete floor of the laboratory space. The AC input wiring consists of type-W cables from the 480VAC 3-phase service. Figure 2 shows a similar example of an EVSE support structure and wiring as used in laboratory testing.

Figure 2. Representative example of an in-laboratory EVSE installation.

1.2 Measurement Parameters

1.2.1 Conductive EVSE Measurement Parameters

For EVSE characterization, approximately 30 parameters are collected using power analyzers and other laboratory-grade sensors to quantify and characterize the system operation. It should be noted that many of the same measurement parameters are similarly described in “EVs@Scale Next-Gen Profiles - EVSE Characterization 2023”[1] and “EVs@Scale Next-Gen Profiles - EV Profile Capture 2023.”[2] These measurements are harmonized with the EV charge profile measurements and are further supported by the addition of a few parameters enabled by using an EV emulator. A few vehicle-specific parameters, such as battery temperature, are omitted as they do not apply to EVSE characterization. Table 1 and Table 2 detail the EVSE characterization parameters. The EVSE unique ID, firmware, and software version parameters have been omitted, or altered, for anonymity in this report and results dataset.

Table 1. EVSE characterization metadata parameters.

Measurement Location	Parameter	Phase	Units
Metadata	EVSE Unique ID	–	–
	EVSE Firmware/Software Version	–	–
	Vehicle Emulator Model / Information	–	–
	Vehicle Emulator ID	–	–
	Timestamp	–	MM/DD/YY hh/mm/ss.dd

Table 2. EVSE characterization measurement parameters.

Measurement Location	Parameter	Phase	Units
480 VAC Input to each Power Cabinet	Voltage	A, B, C	V (RMS)
	Current	A, B, C	A (RMS)
	Frequency	A	Hertz
	Real Power	A, B, C	W (RMS)
	Reactive Power	A, B, C	VAR (RMS)
	Apparent Power	A, B, C	VA (RMS)
	Power Factor	-	—
	Current THD	A, B	%
	Current Harmonics	3rd, 5th, 7th, 9th	—
Ambient Temperature	Temperature	—	°C
Energy Management Source	OCPP Server/E-mobility Service Provider, Other	—	Power transfer request: A or W
Vehicle Inlet Port	Voltage	DC	V
	Current	DC	A
	Power	DC	W
EVSE Charge Pedestal Output	Voltage	DC	V
	Current	DC	A
	Power	DC	W
	DC Current Ripple	DC	%
EVSE Auxiliary System(s)	Voltage	DC	V
	Current	DC	A
	Power	DC	W
EVSE Cable	Cable Temperature	—	°C
EVSE Connector	Connector Temperature	—	°C
EVSE Power Cabinet	Power Cabinet Internal Air Temperature	—	°C

OCPP: Open Charge Point Protocol

1.3 Measurement Locations

This section describes the locations of the measurements taken for each parameter detailed in the previous section. To produce consistent measurements across multiple charger topologies, the measurement locations for each topology under test are explicitly defined. This measurement location definition is consistent for the EV charge profile measurements and the EVSE characterization measurements. Figure 3 depicts the two types of conductive charger topologies used in the Next-Gen Profiles project: paralleled at the dispenser and primary power cabinet. On the left of Figure 3, each power cabinet is DC-coupled directly to the EVSE dispenser; this is considered a paralleled system that is coupled at the dispenser. In the image on the right of the Figure 3, the power cabinets system only has a single DC connection to the dispenser; this is considered a paralleled system that is coupled at the primary cabinet. This difference in topology drives the requirements on the measurement locations for each system to properly characterize the power flow within the charging system.

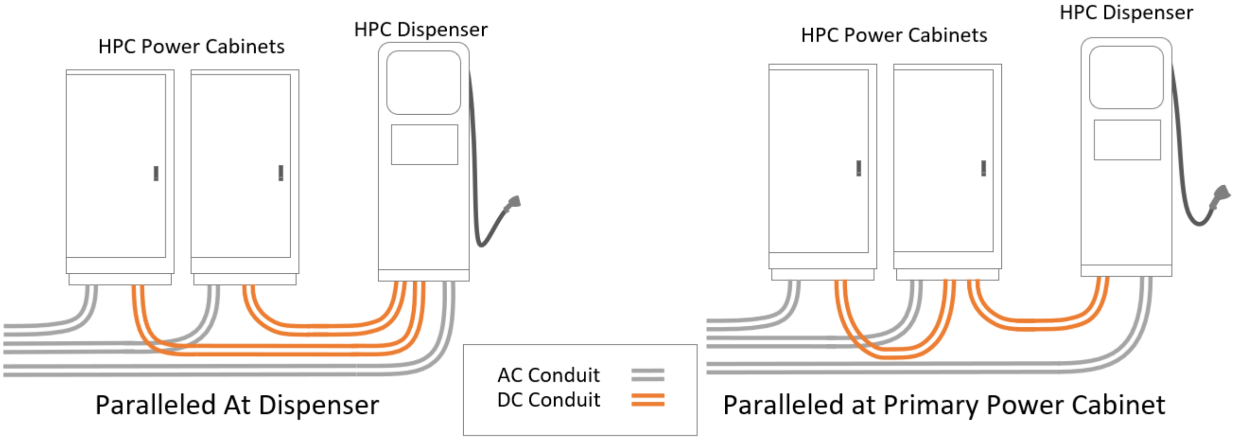

Figure 3. EVSE system topologies.

The AC electrical input to the EVSE is measured at the input to each power cabinet, as supplied from (downstream of) the local service panel and as shown in Figure 4. For three phase measurements, the two-wattmeter method can be employed for some of the charge sessions, and direct measurements of all three phases is also used. The DC output from the EVSE is measured at the EVSE dispenser and at the EV inlet port of the EV emulator.

The auxiliary system measurements in the EVSE include cooling, controls, lighting, and user interface panels among other loads. These measurements are made at the EVSE source location. The DC output and the AC auxiliary power measurement locations at the dispenser are shown in Figure 5.

The temperature measurements for the cable and connector temperatures are obtained from the cable manufacturer's installed thermistors within the cable and connector. The EVSE power cabinet's internal air temperature is obtained by a manufacturer-installed temperature sensor inside the power cabinet.

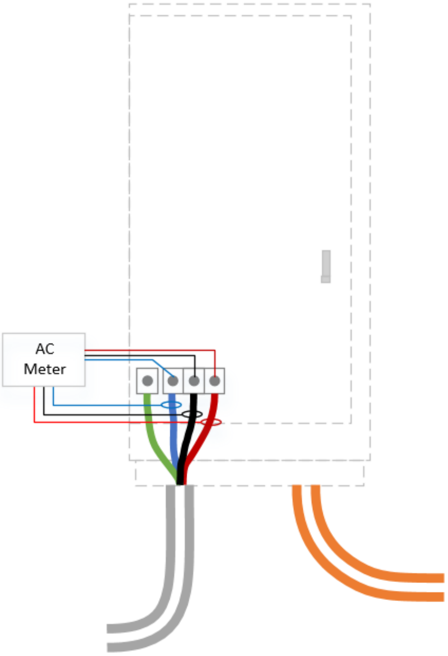

Figure 4. EVSE power cabinet AC power metering.

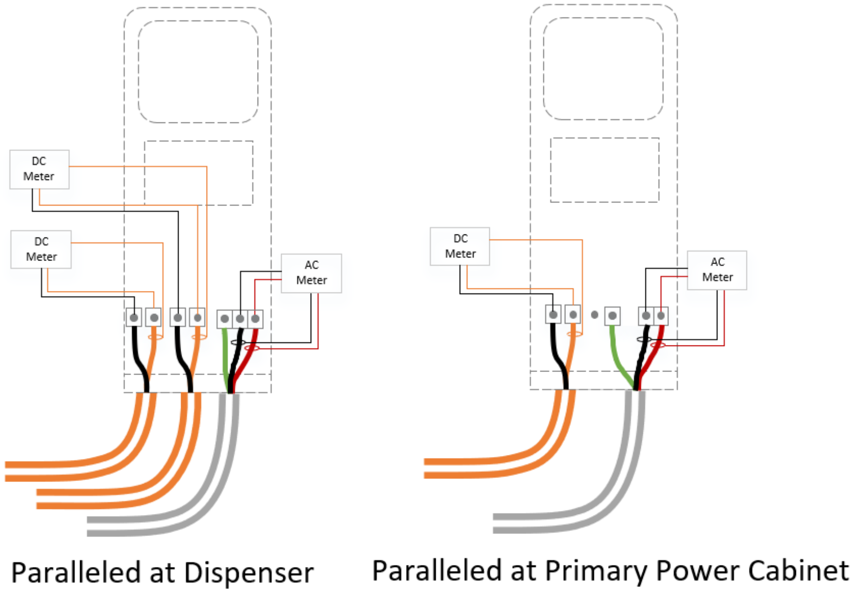

Figure 5. Charge dispenser DC and AC auxiliary power metering locations.

2 EVSE Characterization Testing Conditions and Procedures

2.1 Test Conditions

2.1.1 Conductive V2G EVSE Test Conditions

During EVSE characterization, DC current and DC voltage measurements are made to quantify the operational performance of the EVSE over a wide range of EVSE power transfer conditions. AC voltage characteristics are collected to quantify the full set of expected real-world operating conditions. Table 3 details the DC power transfer conditions during nominal and off-nominal test conditions.

Table 3. V2G EVSE power transfer characterization test conditions.

Test Condition Category	DC Current Test Conditions	DC Voltage Test Conditions	Tolerance
Nominal test conditions	From maximum discharge power transfer to maximum charge power transfer in fifty (+/-10) equally spaced intervals	300V, 400V, 650V, 750V, 850V	+/-5%
Off-nominal test conditions	Discharge 100%, 50% and Charge 50%, 100% power	400V, 850V	+/-5%

For the characterization of the V2G energy management system response of the V2G EVSEs, several requests for change of power transfer are tested to determine the combined system latency and response characteristics to the given request. Table 4 details the required test cases used for the characterization of the V2G capable EVSE response to request of change in power transfer.

Table 4. V2G energy management response characterization initial and final power transfer test conditions.

Initial Power Transfer	Requested Power Transfer				
	Discharge 100%	Discharge 50%	0kW	Charge 50%	Charge 100%
Discharge 100%					X
Discharge 50%				X	
0kW	X				X
Charge 50%		X			
Charge 100%	X				

The test boundary conditions for EVSE characterization of nominal and off-nominal test conditions are detailed in Table 5, including off-nominal ambient temperature conditions, AC grid input conditions, and smart energy management request details. The parameters highlighted in green are the test conditions for the nominal test conditions for EVSE characterization.

A nominal test is conducted under ideal conditions that should transfer the maximum allowable energy in the shortest amount of time possible. The following EVSE parameters must be fulfilled to complete a nominal test: (1) outside ambient temperature must be 23°C, (2) smart charge curtailment values must all be FALSE, and (3) no limits should be placed on the EVSE cabinets or available DC current.

Table 5. EVSE characterization boundary conditions.

Condition Category	Condition Sub-Category	Condition Metric	Tolerance
Temperature	Ambient Temperature	Nominal: 23 °C	+/- 2%
		Hot: 40 °C	+/- 2%
		Cold: -7 °C	+/- 2%
Grid Condition	Voltage	Nominal: 480VAC	+/-25VAC
		Swelled: 528VAC (110% nominal)	+/-25VAC
		Sagged: 432VAC (90% nominal)	+/-25VAC
	Harmonics	Nominal: No Harmonics	—
		5% Voltage Distortion	+/- 1%
	Frequency	Nominal: 60 Hz	+/- 0.2 Hz
		Increased: 61.2 Hz	+/- 0.2 Hz
		Decreased: 58.8 Hz	+/- 0.2 Hz

2.2 Test Procedures

EVSE characterization requires detailed planning, preparation, and execution to successfully acquire accurate and meaningful results for the testing program. This section describes the test procedures and setup requirements for the numerous areas of EVSE characterization.

2.2.1 EVSE Power Transfer Characterization at Nominal Conditions

Measurement parameters are collected across a wide range of DC current and DC voltage test points (quasi-steady-state testing) at nominal test conditions, as detailed in Table 3. The test procedures and requirements for the quasi-steady-state testing are as follows:

- The EVSE will soak at the ambient temperature prescribed for the test conditions for a minimum of four hours prior to the test's commencement.
- The charge session can be continuous for the numerous test points of the quasi-steady-state testing, or the test operator may end the charge session and begin a new charge session as necessary. The EVSE does not need to soak for four hours at ambient temperature again prior to resuming steady-state testing.
- Record the vehicle emulator make/model, EVSE make/model/firmware version, ambient temperature, day/time.
- Data measurements are collected at a rate of 10 Hz.
- Each quasi-steady-state DC current and DC voltage test point is held for a minimum of 180 seconds. This is necessary to ensure the EVSE reaches steady-state operation.
    - Steady state is defined as +/- 0.2 ADC and +/-1 VDC over the final 30 seconds of the 180-second sample period.
- The final 30 seconds of collected data are averaged to determine a single steady-state value for each measurement parameter for each quasi-steady-state test point.

2.2.2 EVSE High-Utilization Characterization

EVSE characterization during repetitive or high-utilization power transfer sessions is conducted to determine the EVSE operational characteristics and power consumption of the EVSE auxiliary control systems. Of particular interest is the combined charging system liquid-cooled cable thermal management system. Three full-power, 10-minute charge sessions are conducted consecutively, with a small rest period between each charge session. This test sequence is representative of three EVs charging consecutively at one EVSE, with little time between charge session. Each charge session is conducted at 750 VDC and 500 AMP (or full power if the EVSE is not capable 500 AMP at the required voltage). In between each charge session, the charge cable is unplugged from the EV emulator and returned to the cable holster on the EVSE charge dispenser. Measurements are taken continuously throughout all seven consecutive test steps as detailed in Table 6.

Table 6. EVSE high-utilization test sequence.

Step #	Duration	Test Condition Category	DC Current Test Conditions	DC Voltage Test Conditions	Tolerance
1	30 s	Plug in and start charge session	Ramp up current to Step #2	—	+/-30 s
2	10 min.	Steady-state power transfer	500 AMP request	750 V	+/-2%
3	240 s	Stop charge session, unplug	0A	—	+/-30 s
4	10 min.	Steady-state power transfer	500 AMP request	750 V	+/-2%
5	240 s	Stop charge session, unplug	0A	—	+/-30 s
6	10 min.	Steady-state power transfer	500 AMP request	750 V	+/-2%
7	30 s	Stop charge session, unplug	0A	—	+/-30 s

- The EVSE will soak at the ambient temperature prescribed for the test conditions for a minimum of 4 hours prior to commencing testing.
- Record the vehicle emulator make/model, EVSE make/model /firmware version, ambient temperature, day/time, etc.
- Data collection of the measurement parameters must be continuous through the entire test sequence:
  - Begin data collection at least five seconds prior to plugging the EVSE into the EV emulator.
  - Continue data collection for at least five seconds after unplugging the EVSE from the EV emulator.
- Data measurements will be collected at a rate of 10 Hz.
- The EVSE high-utilization characterization test sequence must be continuous and uninterrupted, as detailed in Table 6.
- Test steps must be conducted in the order detailed in Table 6. The order of the test steps cannot be changed.
- Do not clear, reset, or reboot any portion of the EVSE or alerts displayed by the EVSE during the test sequence.
  - Take note of any alerts or errors from the EVSE during the test sequence, as part of the data collected.

- If the EVSE is not capable of providing the requested DC current at the specified DC voltage, operate the EVSE at the highest DC current possible at the specified DC voltage test condition.
- After completing the entire test sequence, the EVSE may be rebooted or reset as necessary.

2.2.3 EVSE Characterization at Off-Nominal Ambient Temperature Conditions

Since ambient temperature can potentially impact the performance characteristics of the EVSE, quasi-steady-state testing is conducted at two off-nominal ambient temperature conditions (detailed in Table 5) across the range of DC current and DC voltage power transfer test points detailed in Table 3. The test procedures detailed below are similar to the test procedures for the nominal temperature steady-state testing to ensure the validity of the off-nominal temperature conditions:

- The EVSE will soak at the ambient temperature prescribed for the test conditions for a minimum of four hours prior to commencing testing.
- Record the vehicle emulator make/model, EVSE make/model /firmware version, ambient temperature, day/time, etc.
- Adhere to the test procedures detailed in the "EVSE Power Transfer Characterization at Nominal Conditions*"* section.

2.2.4 EVSE Characterization at Off-Nominal Grid Input Conditions

EVSE off-nominal AC grid conditions characterization is conducted using an AC grid emulator to create the AC input test conditions listed in Table 5. These conditions include voltage deviation, frequency deviation, and voltage harmonics injection. The voltage deviation and frequency deviation test conditions include both sag and swell conditions. Each of the test conditions are characterized independently; no concurrent off-nominal conditions are evaluated. Each off-nominal AC grid input test condition is conducted at the off-nominal DC current and DC voltage power transfer test conditions detailed in Table 3.

The test procedures and requirements for the off-nominal AC input grid conditions testing are as follows:

- The EVSE will soak at the ambient temperature prescribed for the test conditions for a minimum of four hours prior to commencing testing.
- Record the vehicle emulator make/model, EVSE make/model /firmware version, ambient temperature, day/time, etc.
- Data measurements will be collected at a rate of 10 Hz throughout the test sequence.

- The charge session will be initiated at nominal AC input grid conditions.
- Each DC current and DC voltage test point is collected per the off-nominal condition tests of Table 3.
    - Acceptable tolerance for the power transfer prior to entering the off-nominal conditions is +/- 0.2 A and +/-1 V.

The off-nominal condition tests will be performed in accordance with Table 7 for AC voltage deviation testing, Table 8 for AC frequency deviation testing, and Table 9 for AC voltage harmonics injection testing of total harmonic distortion (THD).

Table 7. EVSE voltage deviation test.

Step #	% of Nominal	Voltage L-L (RMS)	Duration (second)
1	100%	480.0	20
2	98%	470.4	3
3	96%	460.8	3
4	94%	451.2	3
5	92%	441.6	3
6	90%	432.0	60
7	92%	441.6	3
8	94%	451.2	3
9	96%	460.8	3
10	98%	470.4	3
11	100%	480.0	20
12	102%	489.6	3
13	104%	499.2	3
14	106%	508.8	3
15	108%	518.4	3
16	110%	528.0	60
17	108%	518.4	3
18	106%	508.8	3
19	104%	499.2	3
20	102%	489.6	3
21	100%	480.0	20

Table 8. EVSE frequency deviation steps.

Step #	% of Nominal	Frequency (Hz)	Duration (sec)
1	100	60.0	20
2	99	59.4	3
3	98	58.8	3
4	99	59.4	3
5	100	60.0	3
6	101	60.6	3
7	102	61.2	3
8	101	60.6	3
9	100	60.0	20

Table 9. EVSE percent voltage harmonics injection steps.

Step #	% Voltage THD Injection	Duration (sec)
1	0.0%	60
2	5.0%	10
3	0.0%	30

- The charge sessions can be continuous for the numerous test points of the testing, or the test operator may end the charge session and begin a new charge session as necessary between each off-nominal test.

2.2.5 EVSE Characterization of V2G Energy Management System

Testing is conducted to characterize each EVSE power transfer latency and response characteristics using their associated V2G energy management system. Both V2G-EVSE9 and V2G-EVSE10 use proprietary cloud-based V2G energy management systems that can be operated from a web-based user interface to schedule power transfer magnitude, direction (charge or discharge), and duration. These systems are used for a minimum of six power transfer change requests across four DC power transfer test conditions, as detailed in Table 4. The test procedures and requirements for the V2G energy management characterization are as follows:

- Record the vehicle emulator make/model, EVSE make/model /firmware version, ambient temperature, day/time, V2G energy management server version, etc.
- Begin a charge session and operate the EVSE at the DC voltage and DC current values detailed in Table 4 off-nominal test conditions for a minimum of 60 seconds.

- Transmit the Table 4 V2G energy management request via the web-based user interface.
- Repeat this test sequence for each DC current and DC voltage condition listed in Table 3 and for each of the six smart energy management curtailment requests listed in Table 4.

3 Power Transfer V2G EVSE Characterization Results and Analysis

Performance metrics and results are quantified from the EVSE characterization data collected from V2G-EVSE9 and V2G-EVSE10. Quantified values include power transfer capabilities, power transfer efficiency, AC power quality, AC phase-to-phase imbalance, auxiliary and subsystem loads and losses, and component temperatures. During select tests, the real power and reactive power of the EVSE are measured before and after charging sessions to determine the standby consumption of the EVSE. The high-utilization test is not conducted on the two V2G capable EVSEs detailed in this report, because the high-utilization test is intended to characterize the thermal management system performance of high-power DC chargers (i.e., 350kW capable EVSE). Since V2G-EVSE9 and V2G-EVSE10 are 50kW-class EVSE and use passively cooled cables, the high-utilization test is omitted from the test sequence.

For V2G operation of commanded power transfer, a cloud-based energy management system is used. The latency and response characteristics of the energy management systems for the V2G EVSEs under test are measured, and the results are presented in this report. This section presents and compares the characterization results of two V2G capable EVSE during nominal and off-nominal test conditions.

For anonymization purposes, measured results of each EVSE have been presented based on rated alternating current (AC) power or rated maximum DC current. This anonymization is important to ensure reverse engineering identification of the systems is not easily accomplished.

3.1 Nominal Test Conditions Results

The nominal test conditions quasi-steady-state efficiency, power factor, phase imbalance, and current total harmonics distortion performance results for V2G-EVSE9 and V2G-EVSE10 are presented in this following section. These comparison results are presented at the operating voltage condition of 400 Volt (V) DC during charging and discharging operation across the range of power transfer test conditions defined in the procedures detailed in Section 2.

Characterization performance results for V2G-EVSE9 and V2G-EVSE10 trend towards higher efficiency and power factor, and lower AC current THD and phase-to-phase imbalance with increasing power transfer. This is consistent with previous EVSE characterization results.[1] The performance characteristics for both V2G-capable EVSEs are generally very consistent when comparing charging to discharging performance of the same EVSE. The main exception to this charge and discharge performance consistency is for V2G-EVSE10 when operating at high DC current. This can be seen by the diverging performance trends when comparing charging to discharging at high-power levels, as shown in Figure 6, Figure 8, Figure 10, and Figure 11. Efficiency results at 400V DC in Figure 6 show a difference of up to 4% when comparing charging and discharging characteristics, when operating at high DC current values. Other notable performance results, including AC THD and power factor, show an undesirable increasing trend for high-power operation, as shown in Figure 10 and Figure 11.

Unlike V2G-EVSE10, V2G-EVSE9 does not have significant performance characteristics differences between charge and discharge operation across the range of power transfer. The exception is the AC current phase-to-phase imbalance is slightly higher during discharge as compared to charge operation, as shown in Figure 11. Overall, the performance results of V2G-EVSE9 are consistent for charge operation compared to discharge operation and generally trend asymptotically towards desirable peak values, such as a power factor of nearly 1.0 and 96% efficiency, when approaching rated power transfer.

Additional V2G-EVSE10 test results for efficiency and power factor are presented in Figure 7 and Figure 9 to further detail the characterization performance differences across the full range of DC voltage test conditions. Above 70% rated DC current, the charge and discharge efficiency characteristics diverge. The peak efficiency of 98.6% occurs while charging near 90% of the rated DC current at the 300V DC test condition. Yet, while discharging at the same test conditions (300V DC and 90% of rated DC), the efficiency is <91%. Additionally, the power factor declines when operating above 70% rated DC, falling below 0.96 during charge or discharge operation over 90% rated DC. For discharge operation at 300V DC, the power factor approaches 0.81 near maximum rated DC.

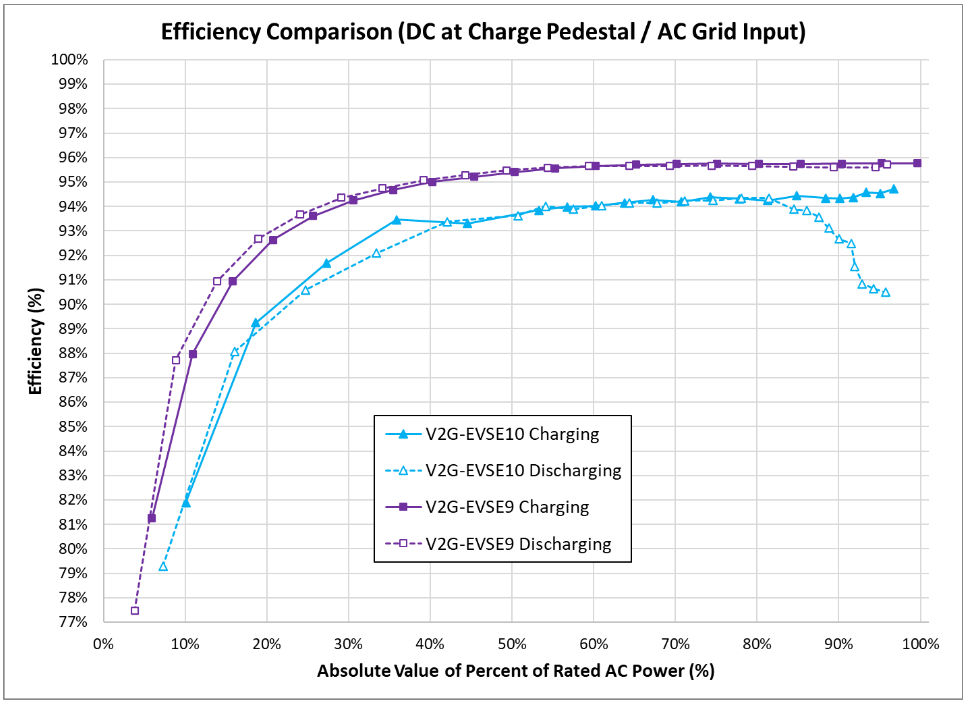

Figure 6. Comparison of AC-to-DC steady-state efficiency at 400V DC during charge and discharge.

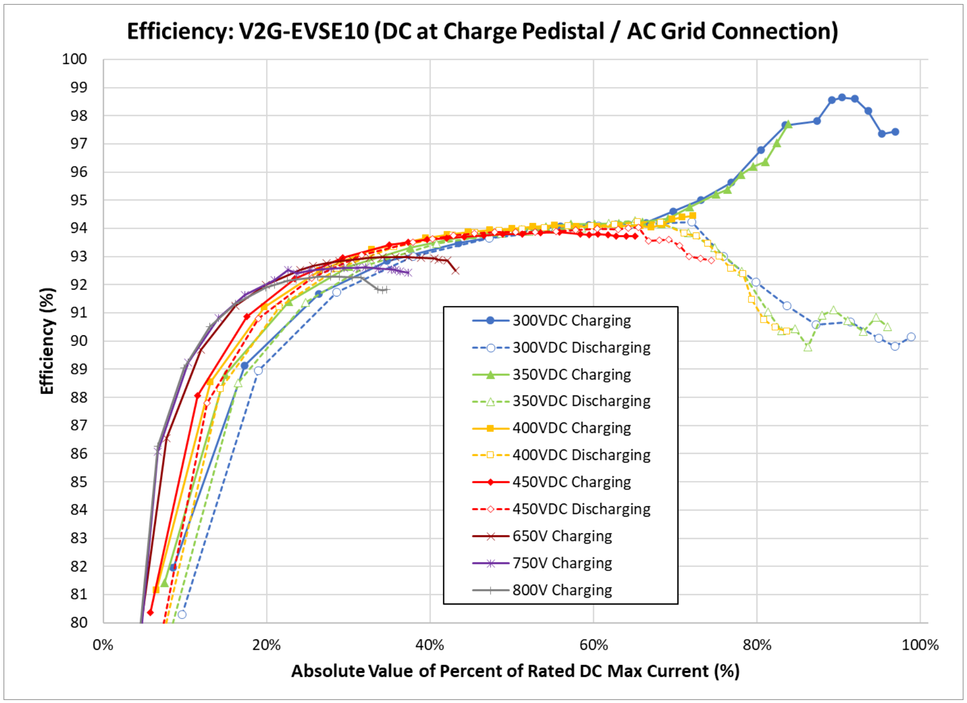

Figure 7. V2G-EVSE10 in-depth AC-to-DC steady-state efficiency results during charge and discharge.

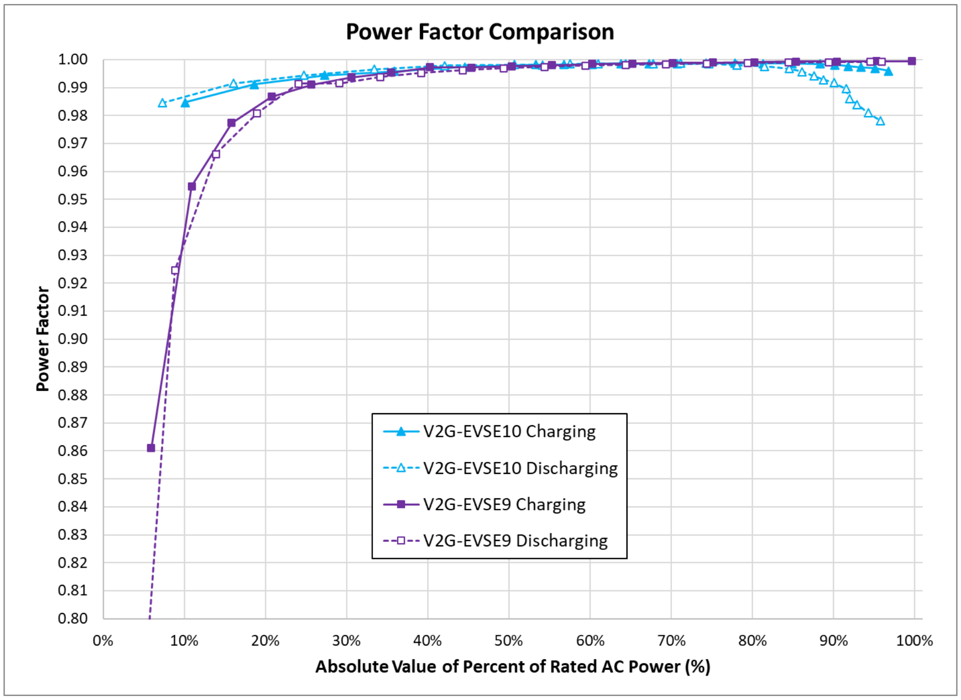

Figure 8. Comparison of power factor during charge and discharge.

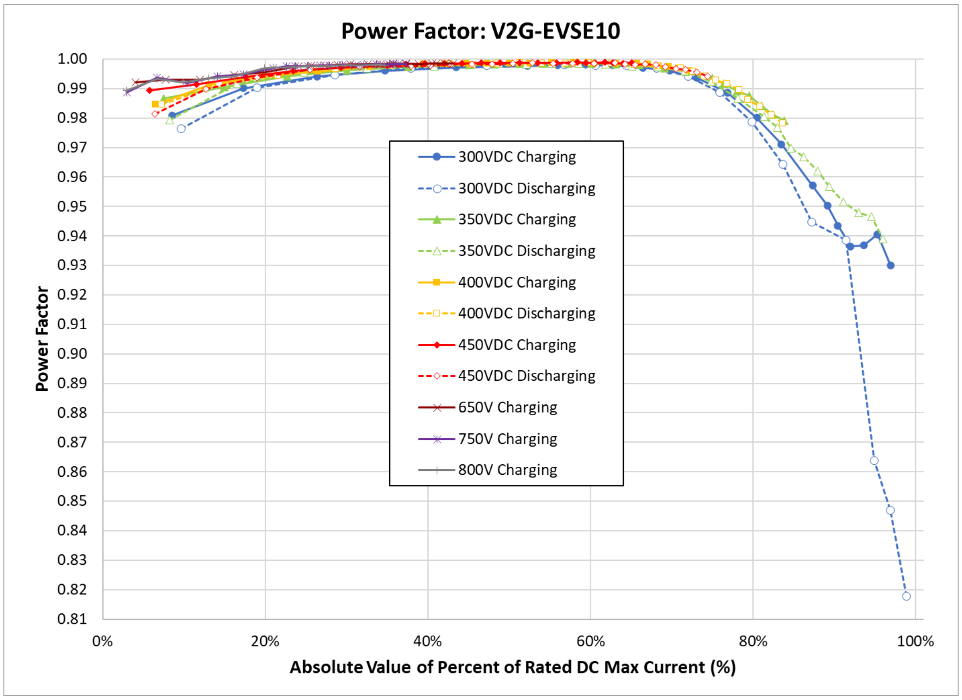

Figure 9. V2G-EVSE10 in-depth power factor results during charge and discharge.

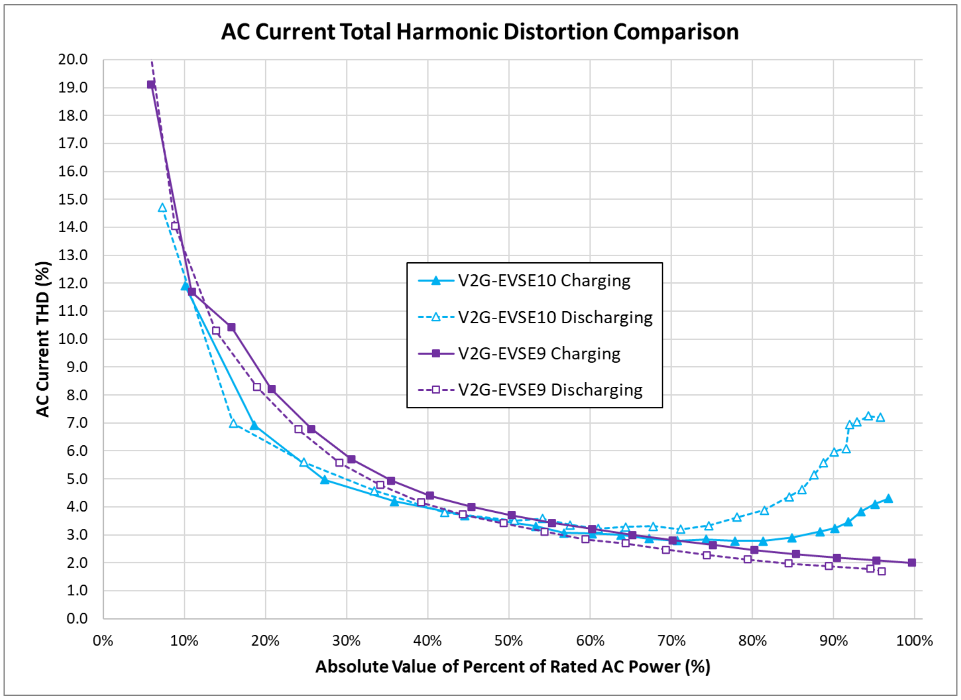

Figure 10. Comparison of steady-state THD on AC current.

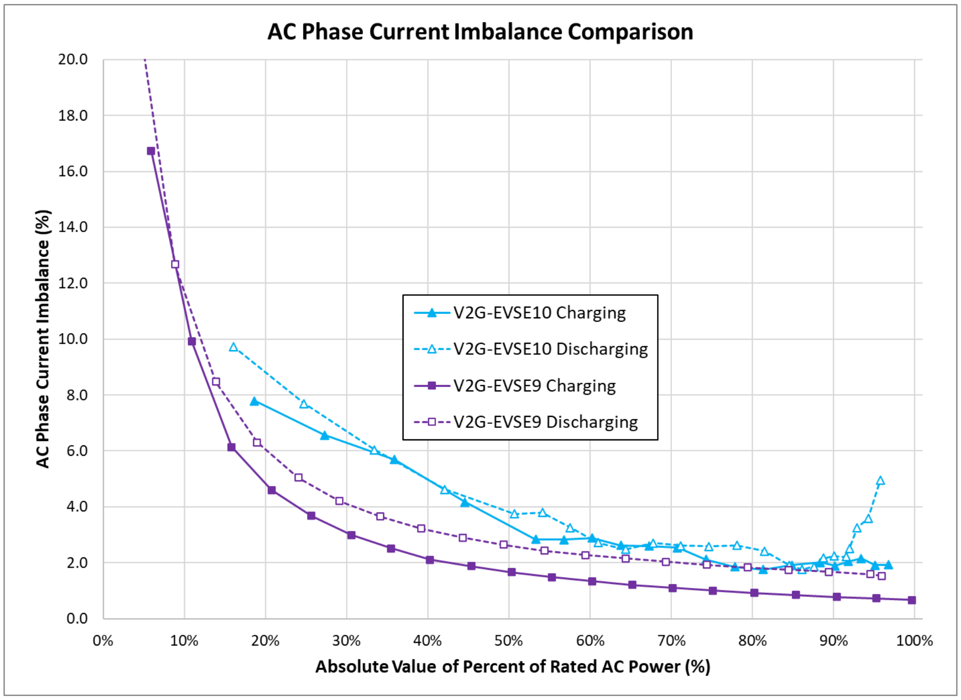

Figure 11. Comparison of AC phase imbalance during charge and discharge.

Under nominal test conditions, after a four-hour soak period, the standby power consumption is measured for each EVSE. Table 10 details the real and reactive power of V2G-EVSE9 and V2G-EVSE10 in standby while not connected to a vehicle and during an active session while no power transfer (i.e., 0 kW requested power transfer). Additionally, auxiliary system power consumption is detailed in Table 10 under typical operating conditions during an active charge or discharge session. The maximum measured auxiliary power is also detailed in Table 10. For both EVSEs, this maximum auxiliary power consumption occurred during high-power transfer, which results in the cooling fans operating at their highest speed.

In comparing the standby power consumption of the two EVSEs when not plugged into an EV, V2G-EVSE9 has only 10W of real power consumption during standby, but the apparent power consumed is over 430VA since reactive power consumption is 430VAR. In contrast, V2G-EVSE10's apparent power is only 249VA, since the real power consumed is 138W and -207VAR of reactive power. Comparing these standby power consumption values to a high-power DC charger previously characterized, EVSE2 (a 350kW-capable, high-power charger) standby power when not plugged into a vehicle is 165W[1] and 280VAR,[1] which is 325VA.

The typical use case for V2G systems is plugged in and in an active charge session. This enables the V2G system to provide energy to the grid or recharge the EV battery to prepare for driving or to prepare for reverse power transfer when needed. Standby power consumption during an active charge session is characterized for both V2G capable EVSEs. As shown in Table 10, V2G-EVSE9 consumes 140W of real power and 250VAR of reactive power, which is 287VA of apparent power. In comparison, V2G-EVSE10 consumes 554W of real power and -4VAR of reactive power, which is slightly more than 554VA. This real and apparent standby power consumption by V2G-EVSE10 is considerably higher than V2G-EVSE9 when in an active session with no power transfer.

Table 10. Standby power draw and auxiliary system power consumption.

Auxiliary and Standby Power Consumption	V2G-EVSE9	V2G-EVSE10
Standby Real Power - not plugged into EV (Watt)	10	138
Standby Reactive Power - not plugged into EV (VAR)	430	-207
Real Power during an active session, plugged into the EV, no power transfer requested (Watt)	140	554
Reactive Power during an active session, plugged into the EV, no power transfer requested (VAR)	250	-4
Typical auxiliary real power during an active session (Watt)	25	570
Max. auxiliary real power during an active session, while cooling fans operating at highest speed (Watt)	40	797

3.2 Off-Nominal Test Conditions Results

The performance of V2G-EVSE9 and V2G-EVSE10 are characterized during AC voltage deviation, AC frequency deviation, and AC voltage harmonics injection test conditions. The testing is conducted at off-nominal test conditions and power transfer levels detailed in Table 3. Off-nominal voltage deviation, frequency deviation, and voltage harmonics have measurable impacts to both V2G-EVSE9 and V2G-EVSE10 performance characteristics for certain off-nominal test cases. A few highly impactful test cases result in the interruption of power transfer or unstable power transfer, while other test cases merely show a negative impact to the power quality results while power transfer continues uninterrupted, and still other test cases show no impact on performance. This section details the off-nominal test conditions findings on V2G EVSE performance characteristics.

Off-nominal ambient temperature characterization is not conducted on the two V2G capable EVSEs due to the lack of available laboratory temperature-controlled facilities.

Characterization of each EVSE's latency and response characteristics to the V2G energy management system commands is conducted for both EVSEs. The results are presented in this section for both ascending and descending changes in power transfer requests.

3.2.1 AC Voltage Deviation

Off-nominal grid conditions characterization is conducted for V2G-EVSE9 and V2G-EVSE10 for AC voltage deviations following the procedures detailed in Table 7. The AC voltage deviation included voltage swell to 518V (300V L-N) and voltage sag to 426V (246V L-N).

V2G-EVSE10 successfully transfers power at all off-nominal AC voltage test conditions. Conversely, V2G-EVSE9 is unable to provide stable power transfer at 300V L-N or above. As shown in Figure 12 and Figure 13, the power transfer for charge and discharge sessions are interrupted for a few seconds followed by the reinitiation of power transfer, and then power transfer interruption again. This inability to consistently transfer power at ≥300V L-N, is the case for both charge and discharge operation. For discharge power transfer recovery during testing, it is necessary for the test operator to reduce the AC voltage below 300V L-N for power transfer to stabilize, as shown in Figure 13. Ultimately, this result indicates that V2G-EVSE9 is unable to properly transfer power for both charge and discharge sessions at or above 300V L-N (a swell of >8% above nominal voltage)

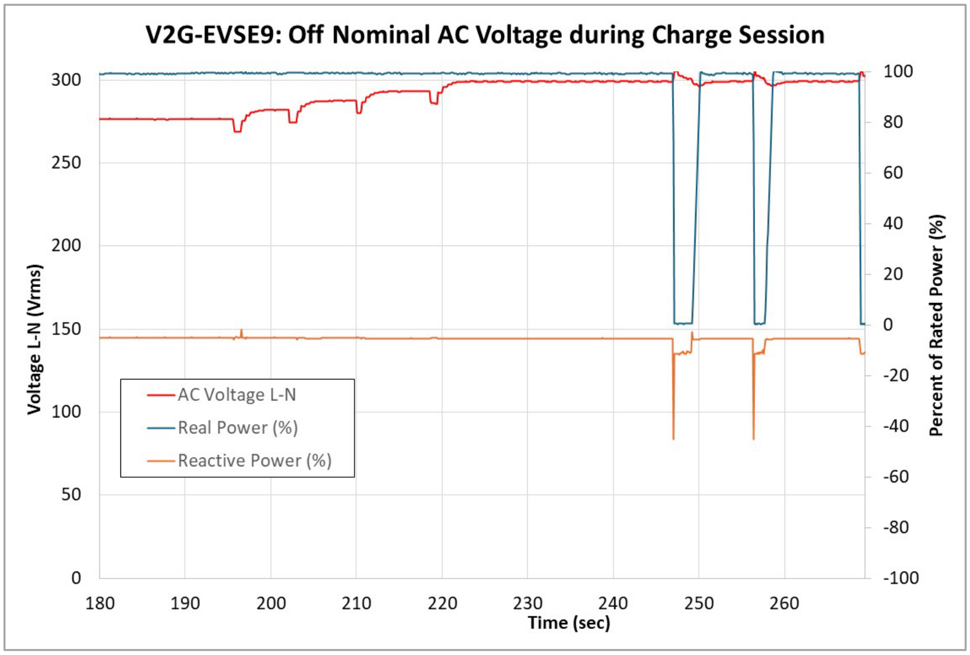

Figure 12. V2G-EVSE9 charge power transfer during off-nominal voltage conditions.

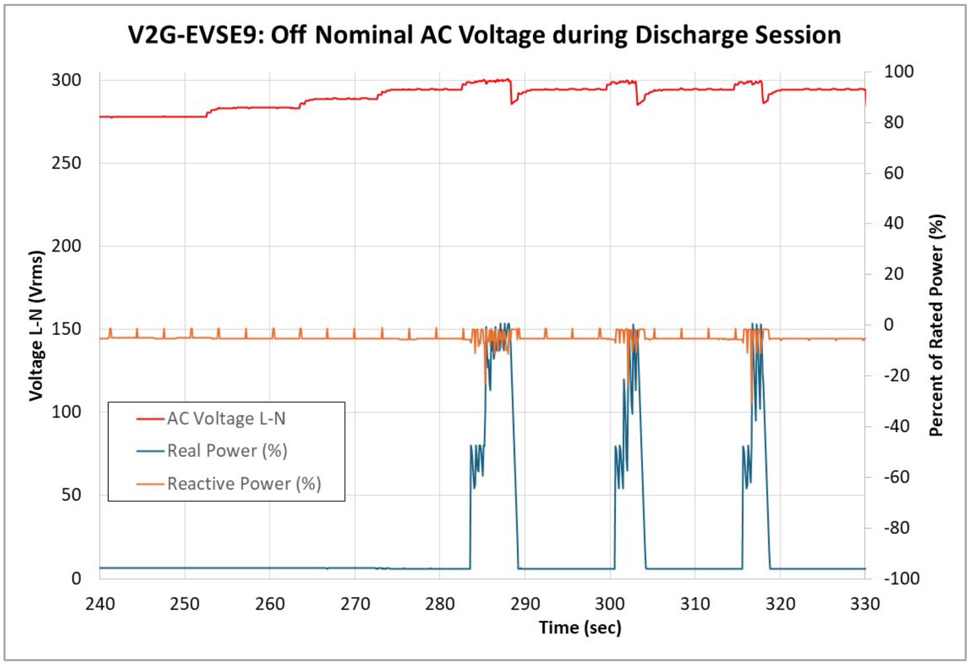

Figure 13. V2G-EVSE9 discharge power transfer during off-nominal voltage conditions.

The V2G energy management systems that are used to control power transfer are different for V2G-EVSE9 and V2G-EVSE10. They differ in their definitions of requested power transfer (i.e., AC power request or DC power request). For V2G-EVSE9 the requested power transfer from the V2G energy management system during charging correlates to AC power transfer request, whereas during discharge operation, the requested power transfer correlates to DC power transfer request. For V2G-EVSE10, the opposite is the case when compared to V2G-EVSE9. The requested power transfer from the V2G energy management system during charging correlates to DC power transfer request, whereas during discharge operation the requested power transfer correlates to AC power transfer request.

Performance results are compared for V2G-EVSE9 and V2G-EVSE10 for both charge and discharge operation, during the off-nominal voltage test conditions, that result in stable power transfer. Figure 14 shows the power transfer capability for the two EVSEs during charge and discharge operation with a 100% power transfer requested by the V2G energy management system. The results from the test cases with unstable power transfer are omitted from the figure. The off-nominal voltage test results show a linearly declining power transfer capability for V2G-EVSE10 below 263V L-N, as shown in Figure 14. This is due to the AC current limitation of V2G-EVSE10.

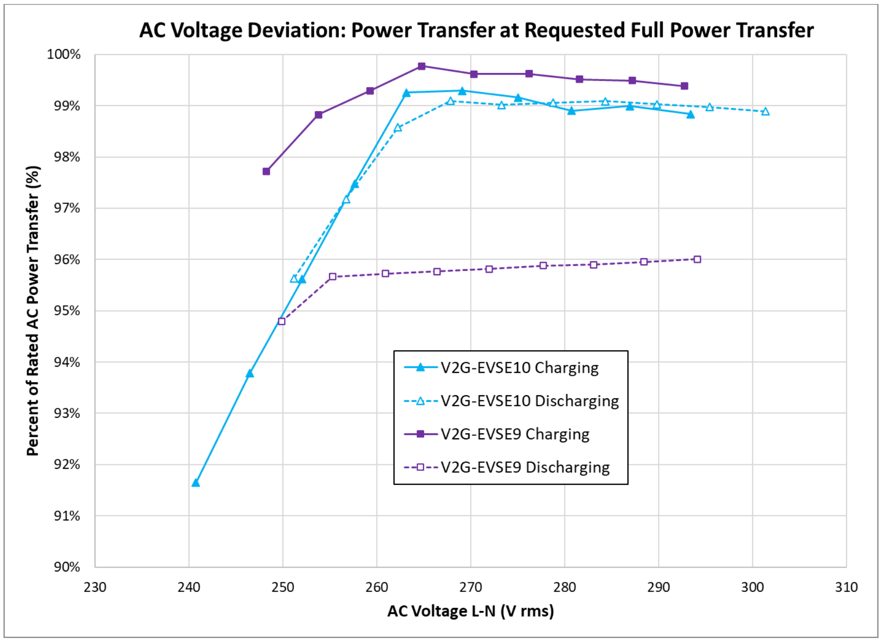

Figure 14. Power transfer results comparison during off-nominal voltage conditions.

In Figure 14, though it appears that V2G-EVSE9 is only capable of 96% of the rated AC power transfer during discharge operation, the DC power transfer is equal to the requested 100% power transfer when operating above AC voltage of 255V L-N. Because the power transfer request correlates to DC power transfer, the resulting AC power transfer is less by the inefficiency of the system. Since the efficiency of V2G-EVSE9 is approximately 96% at the test condition, the AC power transfer during discharge operation is approximately 96% of the rated AC power capability.

For off-nominal testing of V2G-EVSE10, an AC power limitation of the laboratory test equipment that is equal to the rated power of the EVSE, limited the test conditions. During charge operation, a 100% power transfer request correlates to 100% DC power transfer. This results in the AC power exceeding the rated power amount by the system inefficiency (i.e., 105.8% AC power since efficiency is 94.5%). To avoid exceeding the test equipment AC power limits during charge testing, the maximum requested power transfer was limited to 95% power request. With this test limitation, the capabilities of V2G-EVSE10 appear to be the same for charge and discharge, but the AC power transfer capability during charging is slightly higher than the rated power.

Additional performance parameters are compared for V2G-EVSE9 and V2G-EVSE10 during off-nominal voltage conditions. Figure 15 shows the off-nominal AC voltage impact on system efficiency. V2G-EVSE9 shows a very small decline in efficiency with decreasing AC voltage, which trends with losses associated with increased AC current for the power transfer as voltage decreases. V2G-EVSE10 also indicates a negative impact on efficiency from decreasing AC voltage, except for the discharging operation, which shows an improvement in efficiency with decreasing AC voltage below 263V L-N.

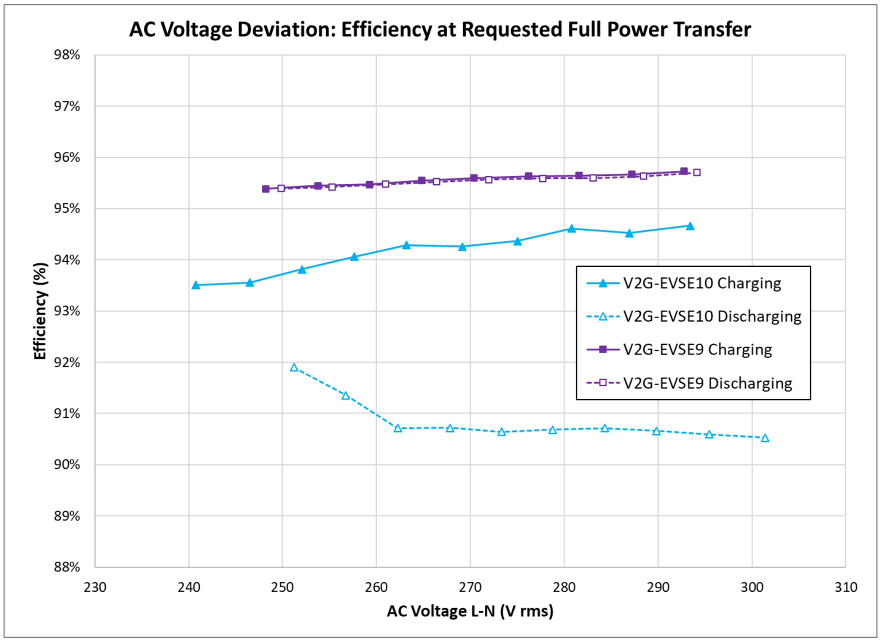

Figure 15. Efficiency results comparison during off-nominal voltage conditions.

Power factor is compared for V2G-EVSE9 and V2G-EVSE10 during off-nominal voltage conditions, as shown in Figure 16. V2G-EVSE9 has negligible power factor impact from AC voltage deviation; however, V2G-EVSE10 shows moderate impact during charging and significant impact during discharging. Again, below 263V L-N appears to have increased impact.

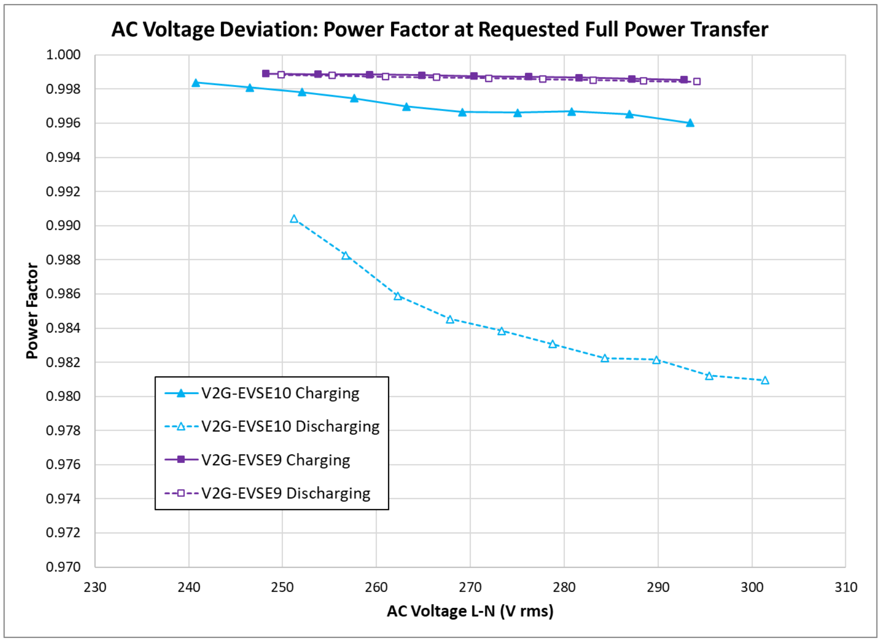

Figure 16. Power factor results comparison during off-nominal voltage conditions.

AC current total harmonic distortion (THD) is also compared for V2G-EVSE9 and V2G-EVSE10 during off-nominal voltage conditions, as shown in Figure 17. V2G-EVSE9 shows very little impact on AC current THD due to AC voltage deviation. In contrast, V2G-EVSE10 shows a nearly 50% increase in AC current THD with increasing AC voltage.

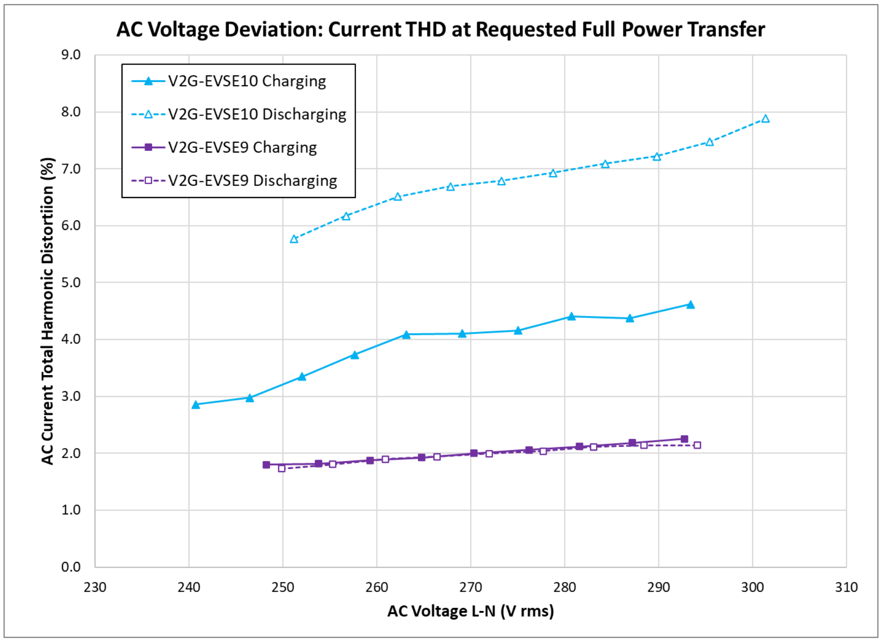

Figure 17. AC current THD results comparison during off-nominal voltage conditions.

3.2.2 AC Frequency Deviation

Off-nominal grid conditions characterization is conducted for AC frequency deviations following the procedures detailed in Table 8. The AC frequency varies between 61.2Hz and 58.8Hz in 0.6Hz steps (i.e., 1% steps) during the charging and discharging operation of the two EVSEs.

During all the AC frequency deviation test conditions for V2G-EVSE9, the DC power transfer is stable, the DC current ripple is low, the power factor is consistent, and the power transfer continues uninterrupted. This is the case for both charge and discharge operation at 50% and 100% requested power transfer. Off-nominal frequency conditions have no measurable impact on the performance characteristics of V2G-EVSE9. In contrast, under the same off-nominal frequency test conditions, V2G-EVSE10 is not able to successfully transfer 50% requested power during charge or discharge operation, for the required 3-second duration of the test plan during any of the off-nominal test points (61.2Hz, 60.6Hz, 59.4Hz, or 58.8Hz). The charge and discharge 100% requested power test conditions are not attempted to avoid any potential risk of equipment damage since power transfer was verified unsuccessful at 50% power during off-nominal frequency conditions.

Additional testing is conducted for V2G-EVSE10 between 60.0Hz and 60.6Hz in 0.1Hz steps to determine the extent of frequency deviation impact. V2G -EVSE10 successfully transferred power for test cases between 60.0Hz and 60.4Hz while charging at 50% requested power, but power transfer ends approximately 5.0 seconds after the frequency is changed to from 60.4Hz to 60.5Hz, as shown in Figure 18.

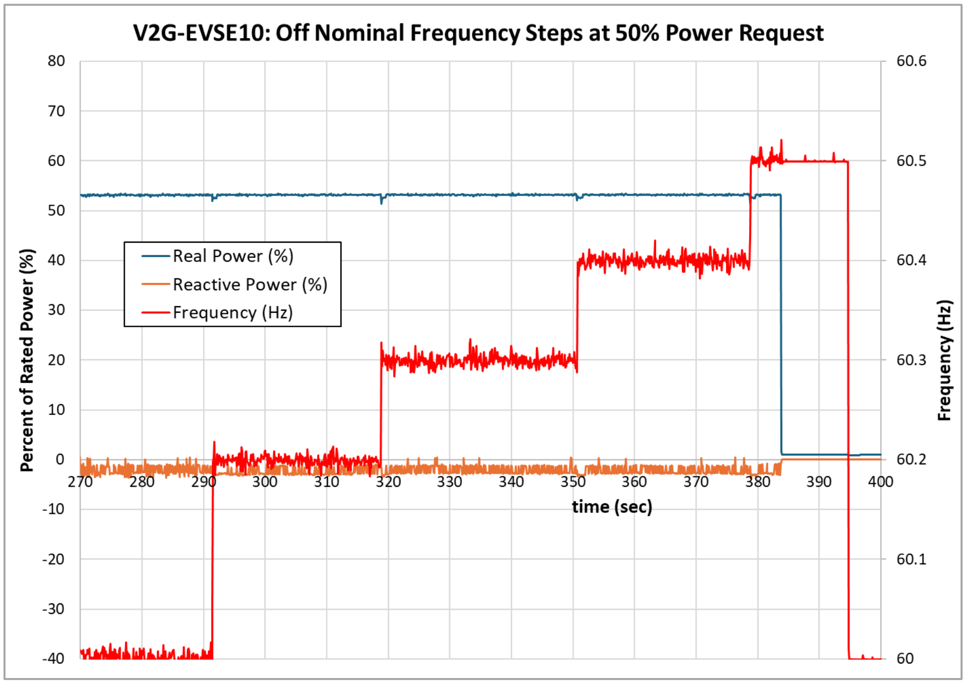

Figure 18. Power transfer during small step changes in AC frequency.

Figure 19 shows the efficiency of V2G-EVSE9 and V2G-EVSE10 during off-nominal frequency conditions. V2G-EVSE9 results show no significant impact on efficiency across the AC frequencies tested. V2G-EVSE10 also shows no significant impact on efficiency for the off-nominal frequency test cases that power transfer is successful. Efficiency results are not available for V2G-EVSE10 at test points above 60.4Hz and below 60.0Hz due to unsuccessful power transfer at AC frequency deviations exceeding ±0.8%.

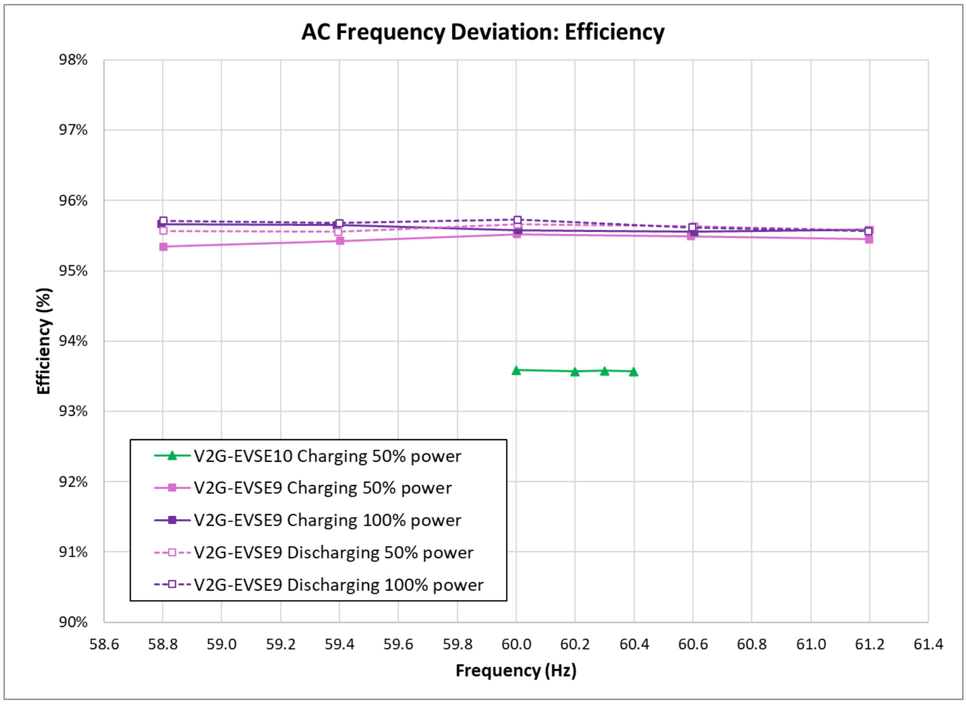

Figure 19. Efficiency results comparison during off-nominal frequency conditions.

Additional testing of V2G-EVSE10 is conducted to determine if a charge session can successfully be initiated at an off-nominal frequency condition, where previously shown unsuccessful when frequency changes during the power transfer session. While the frequency is at 60.6Hz, a charge session is initiated with requested power transfer of 50%. The session did not begin power transfer after successfully completing the standardized session initialization steps including the cable ground-fault check. Conversely, while the frequency is at 59.4Hz, a 50% requested power charge session is attempted and successfully begin power transfer, but the session ended less than eight seconds after reaching steady-state power transfer, as shown in Figure 20. During this session, the three phases of AC current diverged significantly and ultimately resulted in one of the phase currents exceeding the over current protection limit of the AC grid supply, hence ending the session. Luckily, the fuses in the EVSE did not trip even though the phase current briefly exceeded the fuse rating. Overall, the off-nominal frequency characterization quantified the inability of V2G-EVSE10 to transfer power for more than a few seconds, when frequency is <59.6Hz or >60.4Hz (±0.8% deviation).

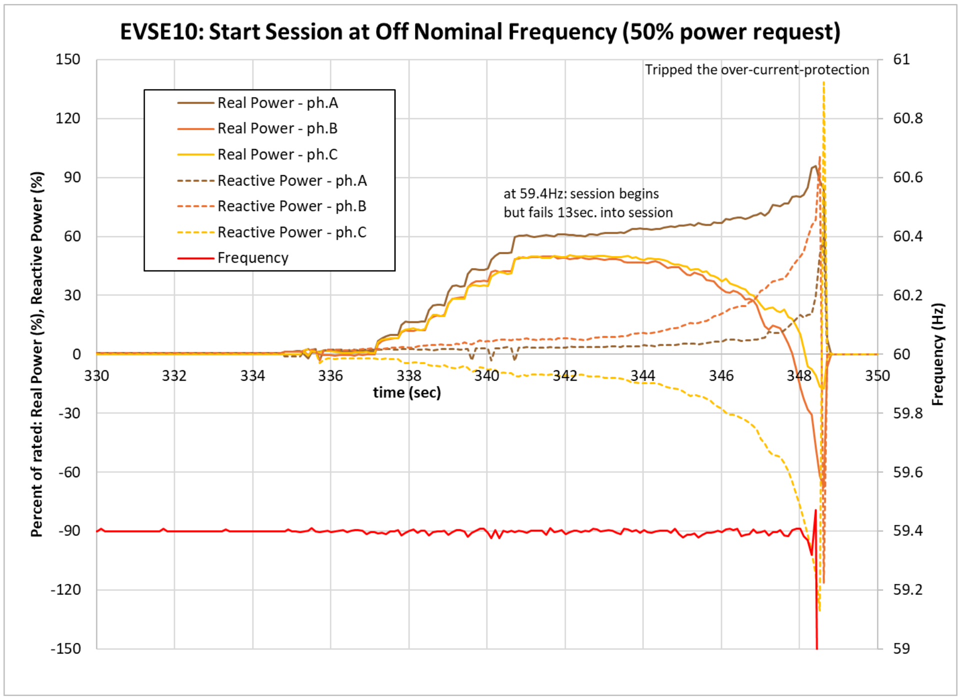

Figure 20. V2G-EVSE10 power transfer instability during off-nominal frequency conditions 59.4Hz.

The “SunSpec UL1741 supplemental guide”[5] details ride-through requirements for equipment when operating during off-nominal AC grid conditions. For off-nominal frequency ride-through, the SunSpec guide specifies continuous operation for frequencies >58.5Hz and ≤60.5Hz, and a ride-through operating for a duration of 299 seconds when frequency is >57.0Hz and ≤58.5Hz and >60.5Hz and ≤62.0Hz. After 300 second duration, the device is to trip. As seen from the off-nominal characterization measurements acquired during laboratory testing for this Next-Gen Profiles project, V2G-EVSE10 does not meet the SunSpec requirements for frequency ride-through capability.

3.2.3 AC Harmonics Injection

Off-nominal grid conditions characterization is conducted up to 5.5% AC voltage harmonics injection during power transfer test conditions following the procedures detailed in Table 9 with additional test points between the minimum and 5.5% test condition to identify performance trends and other interesting outcomes. During the voltage harmonics injection testing, a distorted AC waveform is the AC voltage supplied to the EVSE. The harmonics injection component is primarily the fifth harmonic.

During off-nominal AC voltage harmonics testing of V2G-EVSE9 and V2G-EVSE10 power factor and AC current THD are moderately impacted by the AC voltage harmonic injection. With increasing magnitude AC voltage THD injection, both EVSEs show decreasing power factor and increasing AC current total harmonic distortion, as shown in Figure 21 and Figure 22.

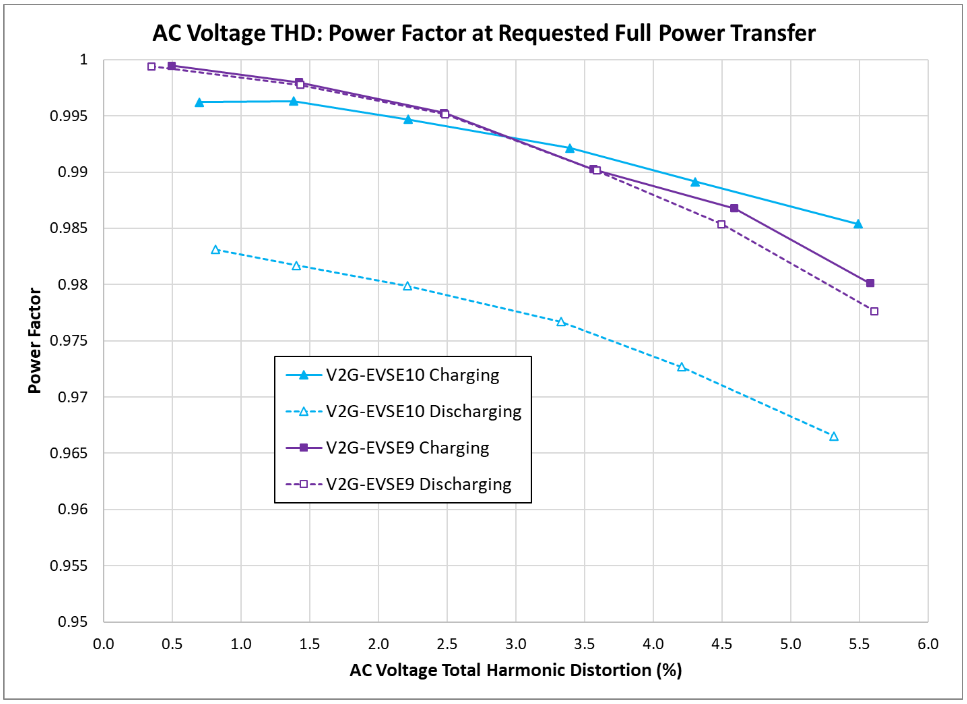

Figure 21. Power factor comparison during off-nominal voltage harmonics conditions.

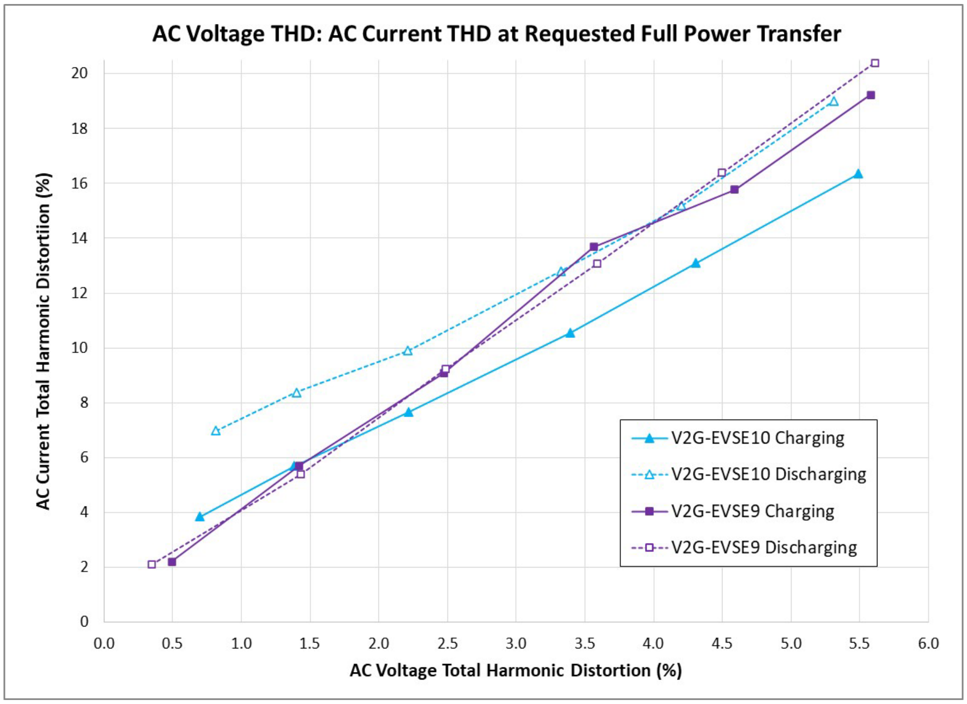

Figure 22. AC current THD comparison during off-nominal voltage harmonics conditions.

3.3 V2G Energy Management Latency and Response Rates

V2G-EVSE9 and V2G-EVSE10 use cloud-based V2G energy management systems that command the power transfer level between the EVSE and EV to optimize energy requirements, power demands, financial costs/revenue, and numerous other factors included in the V2G energy management controls optimization. The V2G energy management systems can either input numerous parameters, such as grid electricity pricing signals, grid loading conditions, and vehicle driving schedule requirements, or the energy management systems can receive manual inputs from a fleet owner/operator to manually schedule or control the power transfer rate for charge or discharge operation. This manual operation is executed via a web-based user interface integrated with the cloud-based V2G energy management system. The V2G energy management system provides command signals via cellular communications to the EVSE. Upon receipt of the power request commands, the EVSE changes power transfer within the EV operating limits.

The latency and response characteristics of the entire system (e.g., web-based user interface, V2G energy management system, cellular communications, and EVSE response) are quantified through laboratory testing for V2G-EVSE9 and V2G-EVSE10. This is accomplished by sending a change in power transfer request via the web-based user interface and by measuring the resulting power transfer response characteristics. This quantifies the latency from the request submission until the measured initial change in power transfer and the ramp rate characteristics, including the magnitude of power transfer change per unit of time. This testing is conducted for all test conditions, including ascending and descending changes in power transfer. Table 11 shows the range and average latency for both EVSEs. Note the considerable difference between the two EVSE's average latencies of 1.0 seconds to 5.7 seconds. Table 11 also shows the ascending and descending ramp rates of the EVSEs. V2G-EVSE9 has the same ramp rate characteristics for both ascending and descending change in power transfer regardless of initial or final value. Conversely, V2G-EVSE10 ramp rates are considerably different for ascending and descending changes in power transfer with a peak ramp rate of two and a half times the rated power of the EVSE per second. This means a change from full charge power to full discharge power can occur in less than one second after an average delay of 5.7 seconds from the time the request is sent.

Table 11. V2G energy management control latency and ramp rates.

Response to Change in Power Transfer Request	V2G-EVSE9	V2G-EVSE10
Average Latency (s)	1.0	5.7
Range of Latency (s)	0.8 to 1.8	3.4 to 8.8
Ascending Ramp Rate (% of rated AC kW/s)	95%	50% to 125%
Descending Ramp Rate (% of rated AC kW/s)	-95%	-90% to -250%

Comparing the transient response rates of these two V2Gcapable EVSE to the transient response rates previously characterized for a high-power DC fast charger[1], EVSE2 ramp rates range from -200.6A/sec to -64.1A/sec descending and 171.7A/sec to 44.8A/sec ascending. This equates to -48.7%/sec to -7.3%/sec descending and 41.7%/sec to 5.1%/sec ascending percent of rated power. At the highest ramp rate scenarios, EVSE2 takes approximately 2 seconds to ramp from 100% power transfer to <15% power transfer. EVSE2[1] has a 2–5 times slower ramp rate than the V2G EVSEs detailed in this report. This is notable in scenarios when multiple V2G EVSEs are controlled concurrently to change power transfer. This may be beneficial by enabling the ability to rapidly respond to immediate grid support requirements. However, if control coordination is not executed correctly, this high response rate of V2G systems may introduce other transient issues or instability, depending on the conditions.

Figure 23 shows the response characteristics of V2G-EVSE9 overlaid on one plot for a request of change in power transfer. Each of the requests were initiated at time = 0.0 sec. on Figure 23. Note the latency until the initial change in power transfer is between 0.8 to 1.8 seconds. Also, note the ramp rates are quite consistent throughout all the test conditions and scenarios.

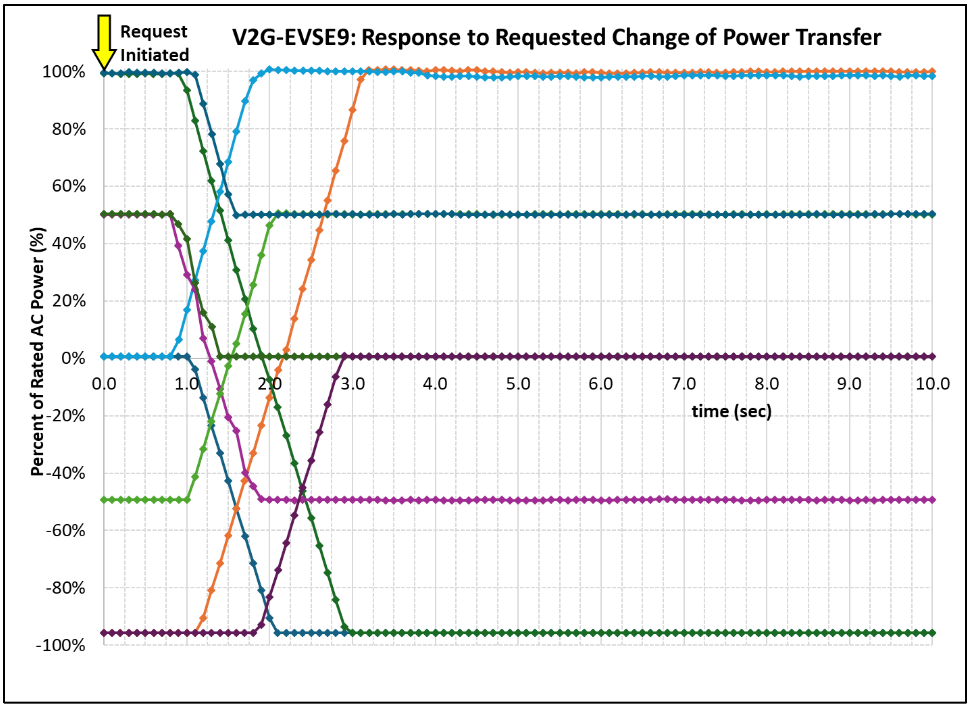

Figure 23. Response to change in power transfer request for V2G-EVSE9.

In contrast, V2G-EVSE10 response characteristics, as shown in Figure 24, are quite different to those of V2G-EVSE9. The latency of V2G-EVSE10 is between 3.4 and 8.8 seconds, and the ramp rates vary from 50% of rated power/second to -250% of rated power/second. One of the plotted results in Figure 24 shows a change in power transfer from 100% charge power beginning at 5.8 seconds and decreasing to 100% discharge power by 6.8 seconds. This supports the details previously discussed in Table 11.

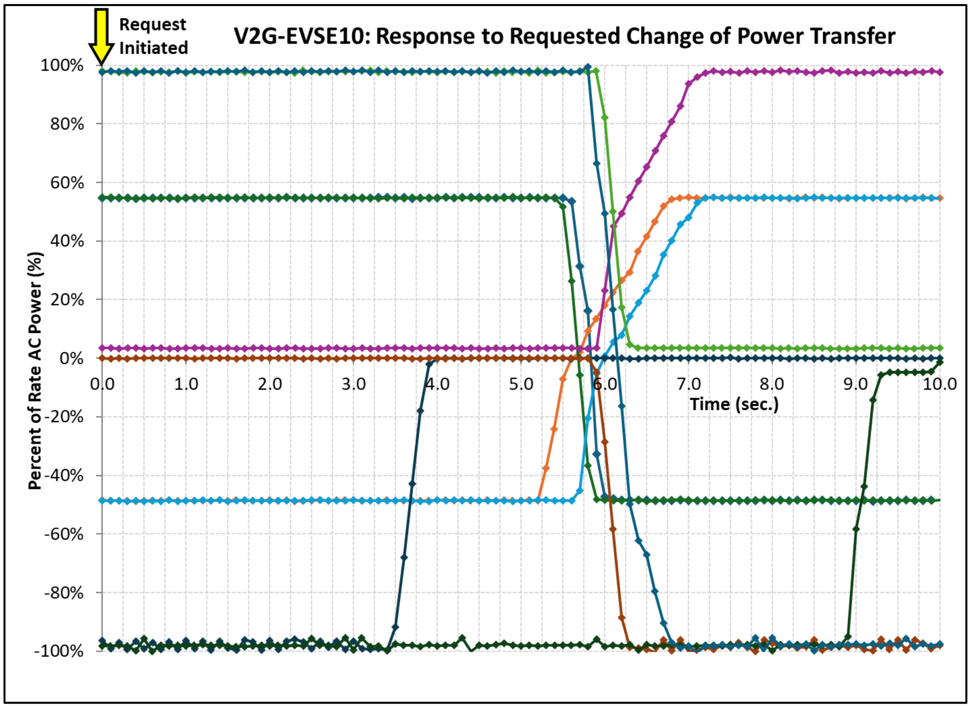

Figure 24. Response to change in power transfer request for V2G-EVSE10.

Since the V2G energy management systems use several communication pathways in series, there is the possibility for significant duration and variation in latency of the systems. Figure 25 details the latency of both EVSEs from the submission of the requested change in power transfer to the initial change in power transfer by the EVSE. This information supports the results presented in Table 11 from the characterization during the change in power transfer events.

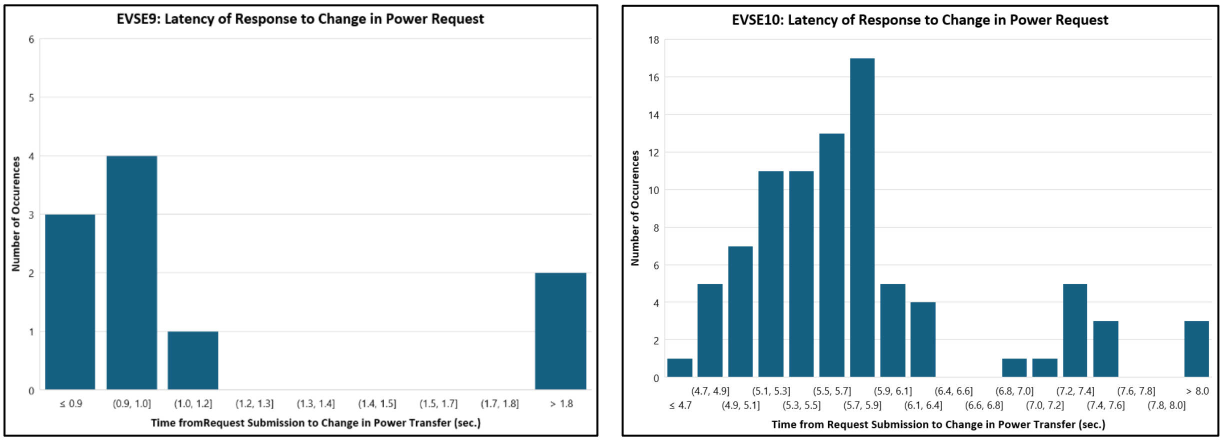

Figure 25. Latency of response to a change in power transfer request.

3.4 Summary of Conductive V2G EVSE Characterization Results and Analysis

V2G EVSE characterization results for V2G-EVSE9 and V2G-EVSE10 are compared across a wide range of operating conditions in support of the U.S. Department of Energy EVs@Scale Consortium Next-Gen Profiles project. The results include steady-state performance characteristics under nominal conditions; off-nominal grid deviation of voltage, frequency, and voltage harmonics; and transient performance during V2G energy management requests of change in power transfer. V2G EVSE characterization highlights the performance attributes of these V2G systems as well as identifies areas requiring further improvement and refinement.

Accurate V2G performance characteristics are needed to design proper control and optimization strategies of energy management for advanced electrified transportation systems, especially when the systems are providing grid support and other energy management services. The results and datasets provided by the EVs@Scale Next-Gen Profiles project are intended to support industry stakeholders, decision makers, modeling and simulation tool development teams, and many other groups developing and deploying advanced electrified transportation systems.

4 References

1. Carlson, B., O. Onar O. 2023. "EVSE Characterization, A Next-Gen Profiles Project Report." OSTI ID:2328073. https://www.osti.gov/biblio/2328073
2. Thruston, S., L. Wells, L. 2023. "EVs@Scale Next-Gen Profiles - EV Profile Capture 2023." OSTI ID: 2293478. https://www.osti.gov/biblio/2293478
3. Thruston, S., L. Wells. 2023. "EVs@Scale Next-Gen Profiles - Fleet Utilization 2023." OSTI ID: 2293479. https://www.osti.gov/biblio/2293479
4. Davidson, K., Kogalur, N. 2024. "EVs@Scale NextGen Profiles: High Level Analysis and Procedures Report." OSTI ID: 2333635. https://www.osti.gov/biblio/2333635
5. SunSpec Alliance. "SunSpec UL1741 Implementation Guide." http://sunspec.org/wp-content/uploads/2015/08/SunSpecUL1741SupplementSAImplemenationGuide.pdf
6. "ENERGY STAR® Program Requirements for Electric Vehicle Supply Equipment Final Test Method for DC-output EVSE." January 2021 https://www.energystar.gov/sites/default/files/asset/document/ENERGY%20STAR%20Version%201.1%20DC%20EVSE%20Final%20Test%20Method.pdf
7. Energy Star. "Gifts that Do a World of Good." https://www.energystar.gov/products/holiday/electric_vehicle_chargers

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