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EVs@Scale: NextGen Profiles EVSE Characterization 2025

Keith Davidson, Darren Paschedag, Isaac Tolbert, Derek Jackson, Pranav Gadamsetty, Namrata Kogalur, Marco Gaxiola, and Saroj Shinde

National Laboratory of the Rockies

The National Laboratory of the Rockies is a national laboratory of the U.S. Department of Energy, Office of Critical Minerals and Energy Innovation, operated under Contract No. DE-AC36-08GO28308.

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NLR/TP-5400-98814
June 2026

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List of Acronyms

A	Ampere
AAC	Ampere, Alternating Current
AC	Alternating Current
ADC	Ampere, Direct Current
CCB	Charge Control Box (Vehicle Simulator)
CCS	Combined Charging System
CCS-1	Combined Charging System, Type 1 (North America)
CHAdeMO	CHArge de Move; Japanese DC charging standard
DC	Direct Current
DOE	U.S. Department of Energy
DRTS	Digital Real-Time Simulator
DUT	Device Under Test
EM	Electromagnetic
EV	Electric Vehicle
EVCC	Electric Vehicle Charge Controller
EVSE	Electric Vehicle Supply Equipment
HPC	High Power Charging
Hz	Hertz
kW	Kilowatt
NGP	NextGen Profiles
NLR	National Laboratory of the Rockies
OCPP	Open Charge Point Protocol
ORNL	Oak Ridge National Laboratory
P	Real Power
PF	Power Factor
Q	Reactive Power
RMS	Root Mean Square
S	Apparent/Complex Power
SAE	Society of Automotive Engineers
SCM	Smart Charge Management
SOC	State of Charge
THD	Total Harmonic Distortion
V	Volts or Voltage
VAC	Volts Alternating Current
WPT	Wireless Power Transfer
XFC	Extreme Fast Charger

Executive Summary

As part of the U.S. DOE EVs@Scale consortium, the *Next-Generation Profiles (NextGen Profiles [NGP])* project presents analysis and results from the characterization of high-power conductive and wireless charging infrastructure. High Power Charging equipment is capable of recharging electric vehicle traction batteries at power levels of 200kW and above.

Electric Vehicle Supply Equipment (EVSE) characterization involves evaluation over a wide range of DC charging currents and voltages during nominal and off-nominal conditions. This evaluation allows for a better understanding of the impact that high-power charging will have on the electric grid. A common set of standard evaluation plans, procedures, and data requirements is documented in *EVSE Characterization: A NextGen Profiles Project Report* (Carlson and Onar 2023), updated in *EVs@Scale: NextGen Profiles: EVSE Characterization 2024* (Kogalur, et al. 2025) and were applied to the characterization in this document with minor updates and improvements. This report covers all electrically conductive power transfer performance characterization activities performed between October 2024 and September 2025 on the Delta Electronics 350kW Electric Vehicle Charging System, consisting of power cabinet model EIDN-U350KTA01 and dispenser model EIDD-U350SSUUAEG-350.

Key Findings include:

- Output regulation
- Efficiency and power factor
- Load management
- Grid resilience
- Smart Charge Management (SCM) performance
- Thermal control system performance
- Multi-port simultaneous charging performance
- Selected performance comparisons with other EVSEs characterized in the NextGen Profiles project.

Hot and cold temperature evaluation was not conducted on the Delta 350kW due to laboratory limitations. Future research could include continued evaluation of the Delta hardware under off-nominal temperature conditions including multi-port/multi-session simultaneous charge analysis, in addition to collecting data on other high-power conductive chargers to augment the data collected for the U.S. DOE EVs@Scale consortium NextGen Profiles project.

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1 EVSE Characterization Introduction

The high-power charging infrastructure performance characterization protocol is performed on production and future charging equipment to better understand the impact of high-power Electric Vehicle Supply Equipment (EVSE) on the electrical grid. These experiments enable current and future modeling efforts by providing accurate, lab-collected performance data.

Using EV emulators, EVSE can be evaluated under repeatable and controlled conditions to simulate, isolate and characterize charging behavior in Direct Current (DC) High Power Charging (HPC) systems. Electrically conductive EVSE power transfer performance characterization aims to explore EVSE performance across nominal and off-nominal conditions over the full DC voltage and current range, including variations in ambient temperature, AC grid input, Open Charge Point Protocol (OCPP) Smart Charge Management/Smart Energy Management curtailment requests, multi-port/multi-session simultaneous charging and conditions of high EVSE utilization. Interoperability and reliability experiments are outside the scope of this report and off-nominal temperature evaluation was not performed due to laboratory limitations associated with nonavailability of required equipment.

This report provides new data and results from the conductive charging EVSE characterization study performed for the U.S. DOE EVs@Scale NextGen Profiles project, which aligns with other reports from this project: *EVs@Scale NextGen Profiles: High Level Analysis and Procedures Report* (Davidson, et al. 2024), *EVs@Scale Next-Gen Profiles - EV Profile Capture 2023* (Thurston and Wells, EVs@Scale Next-Gen Profiles - EV Profile Capture 2023 2023), *EVs@Scale Next-Gen Profiles - Fleet Utilization 2023* (Wells and Thurston 2023). This report updates and complements *EVSE Characterization, A Next-Gen Profiles Project Report* (Carlson and Onar 2023) and *EVs@Scale Next-Gen Profiles -EVSE Characterization 2024* (Kogalur, et al. 2025) and project results will be appended to the Next-Gen Profiles EVSE Characterization dataset (Carlson, et al. 2025).

The Delta 350kW charger has two Combined Charging System Type-1 (CCS-1 or CCS) connectors and is capable of simultaneous charging. To remain compatible with cross-report comparisons of prior work, this report will keep a similar nomenclature. For example, Delta_H1 will refer to CCS-1 connection A, while Delta_H2 will refer to CCS-1 connection B.

Subsequent sections will outline more detail about how the data was collected; *EVSE Characterization, A Next-Gen Profiles Project Report* (Carlson and Onar 2023) and *EVs@Scale Next-Gen Profiles -EVSE Characterization 2024* (Kogalur, et al. 2025) provide more detailed explanations.

1.1 Conductive EVSE Characterization Hardware Configuration

EVSE performance characterization focuses on single port charging performance, with multi-port/simultaneous-session experiments considered as an off-nominal evaluation condition. Figure 1 depicts the equipment utilized for EVSE characterization for single port charging performance including two EVSE power cabinets, one EVSE kiosk (dispenser) and an EV emulator load. Figure 2 depicts the configuration for EVSE characterization of multi-port/multi-session charging performance with a two EVSE power cabinets, one EVSE kiosk (dispenser) and dual

liquid-cooled CCS connectors, which are utilized with separate and independent EV emulator loads. EV emulator use enables repeatable experiments across a wide range of evaluation conditions and accelerates performance characterization efforts by obviating time required for battery discharge.

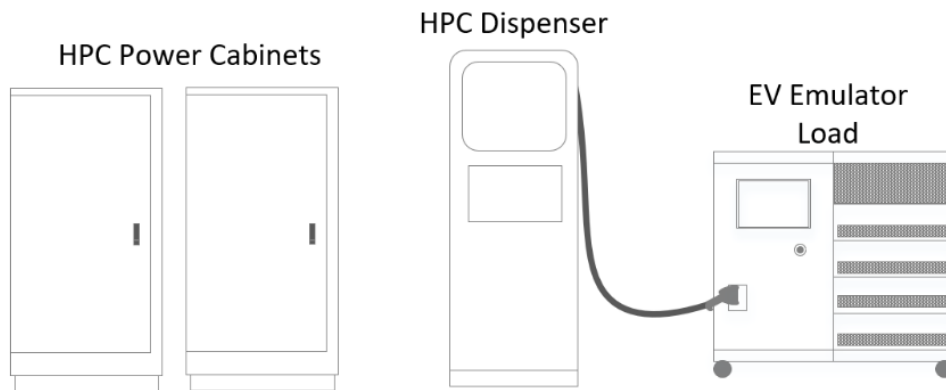


Figure 1. EVSE Performance Characterization Equipment for Evaluating Single Port Charging Performance

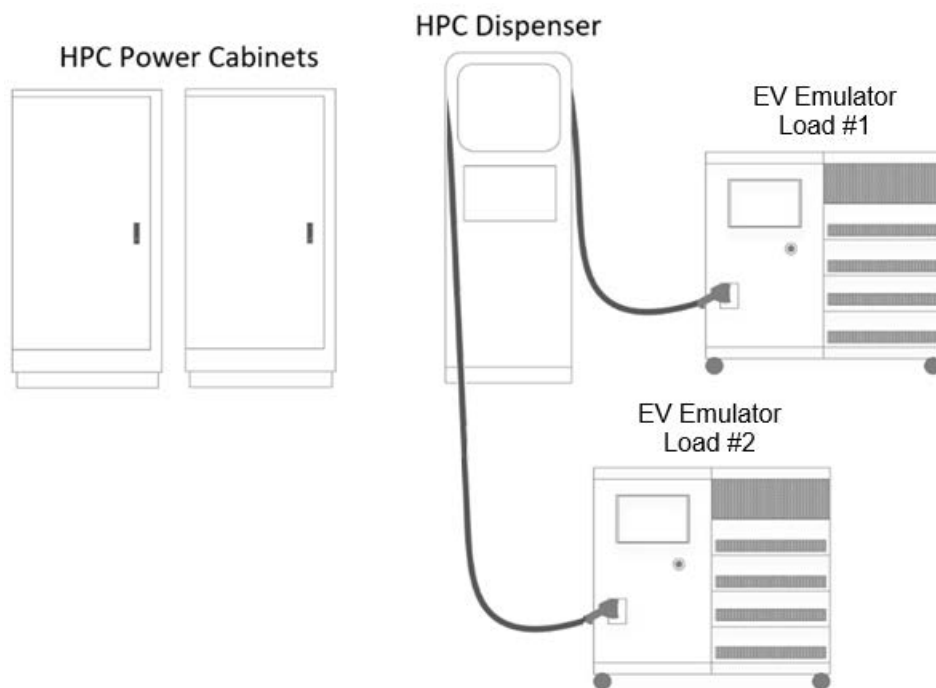


Figure 2. EVSE Characterization Equipment for Evaluating Multi-Port/Multi-Session Charging Performance

The EVSE system is the Device Under Test (DUT) for EVSE performance characterization and is set to standard manufacturer settings without modification. For a detailed list of metrics captured during EVSE performance characterization please see Appendix A. Every attempt is made to instrument the DUT to capture the metrics listed. The location of these measurements is described in Section 1.3 Measurement Locations.

The Delta 350kW EVSE studied for this publication is comprised of one power cabinet and one kiosk (dispenser) equipped with two CCS-1 liquid-cooled cables which operate on independent channels so two EVs can be charged simultaneously. The EVSE is capable of a maximum charging power of 350kW for one CCS-1 connection, which can be split between both CCS-1 connections for simultaneous charging. The Delta is installed in a laboratory setting on an aluminum pedestal to support the enclosures and enable the installation of the necessary wiring without modifying the laboratory floor. All EVSE field wiring is installed in accordance with manufacturer specifications, National Electric Code requirements and best practice.

1.2 Measurement Parameters

1.2.1 Conductive EVSE Measurement Parameters

Approximately 30 parameters from Appendix A are collected using power analyzers and other laboratory-grade sensors to quantify the system operation for EVSE characterization. Many of the collected parameters are also collected during EV profile capture as described in *EVs@Scale Next-Gen Profiles - EV Profile Capture 2023* (Thurston and Wells, EVs@Scale Next-Gen Profiles - EV Profile Capture 2023 2023) and *EVs@Scale Next-Gen Profiles - EV Profile Capture 2024* (Thurston, Wells and Ratrout, et al. 2025). A few vehicle-specific parameters, such as battery temperature, are omitted as they do not apply to EVSE characterization. Other EV emulator-specific parameters are recorded to quantify system performance. The Energy Management Source Curtailment Request is only recorded during smart charge management (SCM) evaluations.

1.3 Measurement Locations

Measurement locations for each topology evaluated are explicitly defined to produce consistent measurements across multiple EVSEs, which can vary in configuration and number of equipment enclosures. Measurement locations are consistent for parameters that are collected in both EV charge profile capture evaluations and the EVSE characterization evaluations. Figure 3 depicts two types of conductive charger topologies for single port charging characterized during the NextGen Profiles performance characterization activities: paralleled at the kiosk (dispenser) and paralleled at the power cabinets. On the left of Figure 3, each power cabinet is DC-coupled directly to the EVSE kiosk (dispenser); this is considered a paralleled system that is coupled at the kiosk (dispenser). In the image on the right of Figure 3, the power cabinets system only has a single DC connection to the kiosk (dispenser); this is considered a paralleled system that is coupled at the power cabinets. Figure 4 depicts an example topology for multi-port/multi-session charging characterized during the NextGen Profiles project where separate DC circuits for CCS Channel A and CCS Channel B are routed between the HPC power cabinet and HPC dispenser. The differences in topology drive variations in measurement locations to properly characterize the power flow within the charging system. It is noted that the Delta 350kW EVSE consists of a single HPC power cabinet and single HPC dispenser.

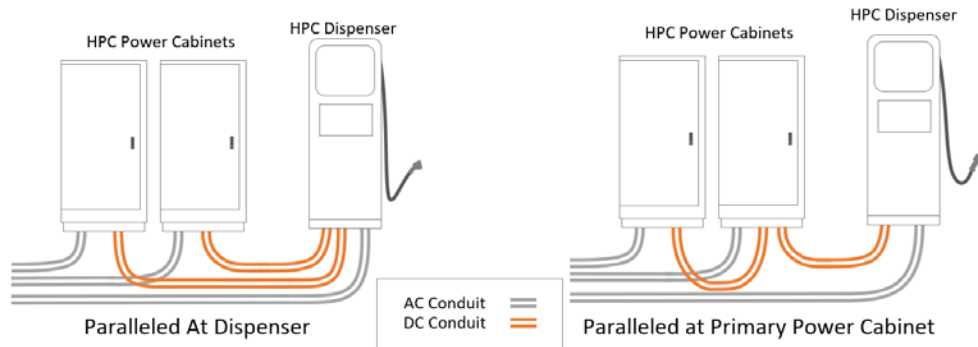


Figure 3. EVSE System Topologies for Single Port Charging

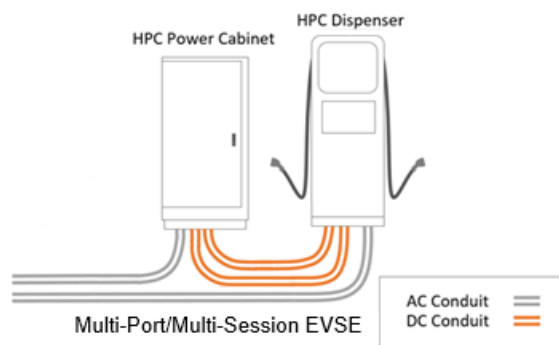


Figure 4. Example EVSE System Topology for Multi-Port/Multi-Session Charging

The AC electrical input to the Delta is measured at the input to the power cabinet downstream of the local service panel; shown in Figure 5. Three phase measurements were collected utilizing a direct measurement of all three phase voltages and currents in addition to the ground current present in the three-phase input. Voltages were measured directly without potential transformers; currents were measured using Hioki CT9693 clamp-on current transformers. The DC output from the EVSE was measured at the EVSE kiosk (dispenser) for both CCS channels and measured at the EV inlet port of the EV emulator(s) as shown in Figure 6. Also shown are EVSE auxiliary system measurements, including cooling, controls, lighting, and front touch panels among other loads. These measurements are made at the EVSE auxiliary power source location using direct voltage measurements without potential transformers, AEMC MR527 clamp-on current transformers for DC current and AEMC MN261 clamp-on current transformers for auxiliary AC current.

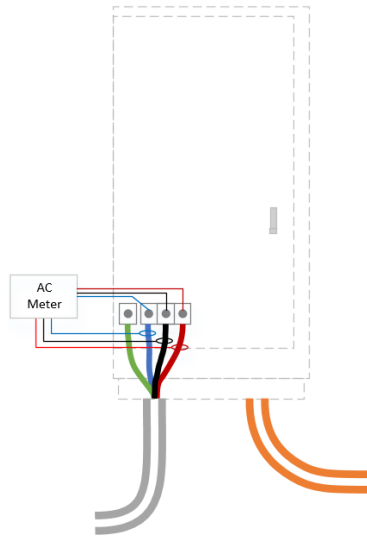


Figure 5. EVSE Power Cabinet AC Power Metering

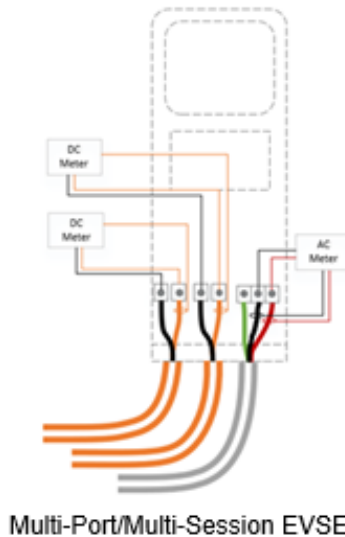


Figure 6. Multi-Port/Multi-Session Charge Kiosk (Dispenser) DC and AC Auxiliary Power Metering Locations

Cable and connector temperatures are obtained from the cable manufacturer's installed thermistors within the CCS cable and CCS connector. The EVSE's cable temperature sensor is located at the surface of the charge cable, where it terminates at EVSE factory-installed buswork. The CCS connector temperature sensor is located inside the CCS connector adjacent to the DC pins in the CCS connector. For the Delta 350kW EVSE, laboratory telemetry could not be collected from built-in sensors directly; CCS cable and connector temperatures were downloaded from the EVSE kiosk portal at reduced sample frequency and precision. The EVSE power cabinet's internal air temperature is obtained from a temperature sensor installed inside of the power cabinets.

2 EVSE Characterization Testing

2.1 Test Conditions

During nominal conditions EVSE characterization, emulated vehicle traction battery DC voltage is set to one of several predefined values listed in Table 1 and DC current is stepped in 10A intervals from 50A up to the maximum available EVSE DC charging current to capture the entire EVSE operating performance envelope. Off-nominal EVSE performance characterizations are performed under conditions where ambient temperature, grid input voltage, frequency, and harmonics, OCPP Smart Charge Management response, multi-port/multi-session charging and thermal control system variables are varied to collect system performance that together forms a set of expected real-world operating conditions. Table 1 summarizes the DC power transfer conditions for all NGP EVSE performance characterization nominal and off-nominal experiment conditions.

Table 1. EVSE Power Transfer Characterization Test Conditions

Test Condition Category	DC Current Test Conditions	DC Voltage Test Conditions	Tolerance
Nominal and Off-nominal temperature experiment conditions	50 to 500 A in 10A increments (up to maximum power)	300 V, 400 V, 650 V, 750 V, 850 V	+/-2%
All other Off-nominal experiment conditions	150 A, 500 A (or full power if 500 A is not possible)	400 V, 850 V	+/-2%

Boundary conditions for EVSE characterization during nominal and off-nominal experiments are summarized in Table 2. Nominal EVSE evaluation condition parameters highlighted in blue, with all other off-nominal EVSE evaluation condition parameters unemphasized.

Table 2. 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%
Multi-Port/Multi-Session	Concurrent charge sessions	Nominal: Single charge session	-
		Simultaneous charge sessions	-
Grid Condition	Voltage (Line-Line)	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

Condition Category	Condition Sub-Category	Condition Metric	Tolerance
		Decreased: 58.8 Hz	+/- 0.2 Hz
Charge Management	Smart Charge Request	Nominal: None	-
		<i>TxProfile</i>	-
		<i>TxDefaultProfile</i>	-
		<i>ChargePointMaxProfile</i>	-
	Smart Charge Request Duration	Nominal: None	-
		2 minutes	+/- 1 minute
	Smart Charge Request Scheduling	Nominal: None	-
		1 minute into charge session	-
	Current or Power Request	Nominal: None	-
		65A (AC RMS Line Input Current)	-
		54kW (AC or DC as implemented by manufacturer)	-

A nominal experiment is conducted under ideal conditions that transfers the maximum possible energy in the shortest amount of time possible. All nominal conditions EVSE performance characterizations are performed by lining up the EVSE to a grid simulator that provides input 3-phase 60Hz power in the form of a pure 277 VAC line-to-neutral (phase voltage) sine wave where all three phases are 120 degrees out of phase with each other. The following requirements must be met to complete a nominal conditions experiment:

- Ambient temperature is 23°C ±2°C
- Grid AC conditions are 277VAC, 60Hz, no grid harmonics
- All smart charge management power or current curtailment values are inactive
- Only one charge session occurs at a time
- No limits are placed on the EVSE cabinets or available DC current

The block diagram in Figure 7 shows an overview of the general evaluation setup which offers a clear understanding of the key pieces of the equipment used and their connections. This diagram also highlights the equipment placed inside the thermal chamber during off-nominal temperature performance characterization.

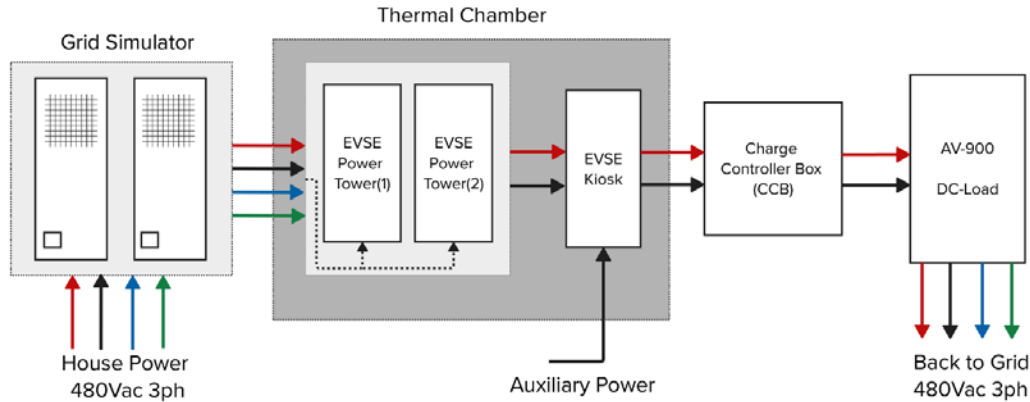


Figure 7. Block Diagram of Experiment Setup for EVSE Performance Characterization

AC measurements at the power cabinets and DC measurements at the kiosk (dispenser) are performed using two different instruments and data from the Charge Control Box (CCB) vehicle simulator is collected from a digital real-time simulator (DRTS). The clocks between these three instruments are synchronized via a 10Hz TTL clock signal output by the DRTS. AC and DC current signals are redundantly recorded on all three devices to synchronize readings on multiple data logging devices to ensure all required experiment signals are recorded with high accuracy. All OCPP commands are logged with timestamps in a local cloud influxDB instance which is synchronized with SNTP to determine EVSE response latency to OCPP SCM command.

Off-nominal smart charge management response experiments are conducted using OCPP 1.6j for the current and voltage evaluation conditions of Table 1. EVSE Power Transfer Characterization Test Conditions. The smart charge management curtailment requests include *TxProfile*, *MaxChargePoint* and *TxDefaultProfile* which are used for NextGen Profiles SCM experiments to send curtailment commands of 54kW or 65A for as many as three curtailment profiles for each of the four off-nominal Table 1 DC power transfer experiment conditions. The smart charge management curtailment requests determine how power and/or current limits are applied and prioritized where *TxProfile* is a per-charge session charging profile with the highest priority, *MaxChargePoint* is a station- or connector-level ceiling with lowest priority that defines the EVSE upper boundary of operating current or voltage and *TxDefaultProfile* is an enduring default profile with medium priority.

2.2 Test Procedures and Results

2.2.1 EVSE Characterization at Nominal Conditions Power Transfer

2.2.1.1 Procedure

During nominal conditions EVSE characterization, emulated vehicle traction battery DC voltage is set to one of several predefined values listed in Table 1 and DC current is stepped in 10A intervals from the maximum available EVSE DC charging current to 50A where each current step is no shorter than 180 seconds to allow the EVSE operating condition to stabilize into a quasi-steady state condition. The evaluation procedures and requirements for the quasi-steady-state experiments are as follows:

- The EVSE will soak at the ambient temperature ($23^{\circ}\text{C} \pm 2^{\circ}\text{C}$) for a minimum of four hours prior to experiment commencement.
- The charge session can be continuous for the numerous evaluation parameters of quasi-steady-state experiments, or the 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 evaluations.
- 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 evaluation 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 evaluation point.

2.2.1.2 Results

2.2.1.2.1 Output Regulation and Ripple Content

Effective DC output regulation is important for ensuring controllability, efficiency, and battery longevity during charging. Steady state deviation from commanded currents and ripple content on the DC output are used as key metrics to evaluate the output regulation of the EVSE. Table 3 demonstrates that the Delta 350kW EVSE exhibits very low steady-state errors across the evaluated DC voltage and current range at nominal temperature of 23°C at 650VDC. It is observed that the largest magnitude DC current error is supplied at low DC load levels, i.e., ≈ 50 ADC. RMS current error of 1.5A across the entire range of EVSE operation is indicative of exceptionally good EVSE current regulation when compared to the DC output current regulation and DC output current ripple requirements of the SAE J1772 standard (Society of Automotive Engineers 2025) and IEC 61851-23 standard (International Electrotechnical Commission 2023).

Table 3. Quasi-Steady State Error on DC Output Current

EVSE	DC Current Steady State Error			
	Minimum [A]	Maximum [A]	Mean [A]	RMS [A]
Delta 350kW	-10.002	5.378	0.572	1.513

Regarding ripple content, Figure 8 illustrates the fluctuations around the steady state output currents for the Delta 350kW EVSE across the operating range at 300VDC and nominal temperature of 23°C . The Delta 350kW EVSE has ripple levels below 2% for much of the operating range until the supplied current falls below ≈ 110 ADC, where ripple increases to as much as $\approx 4\%$ at 50ADC. It is observed that the magnitude of low load output DC current ripple increases as DC output voltage increases. At high levels of charging load, the output DC current ripple is largely independent of DC output voltage.

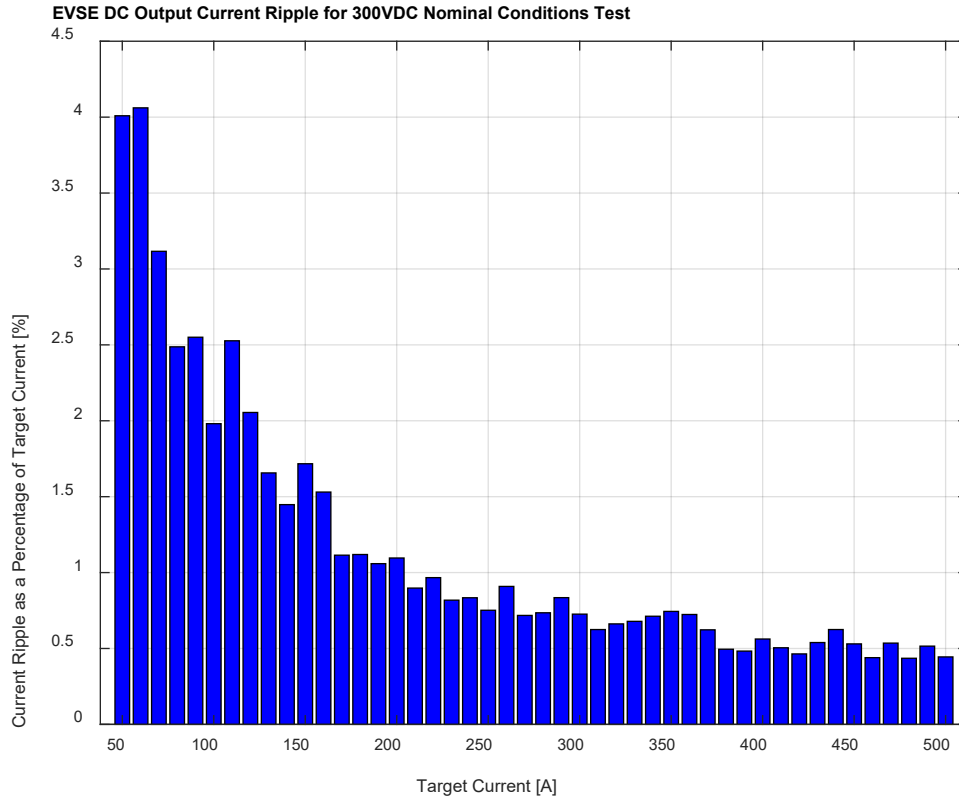


Figure 8. EVSE DC Output Current Ripple for 300VDC Nominal Conditions Experiment

2.2.1.2.2 Efficiency Results

As the number of EVs on the road grows, EVSE manufacturers face the challenge of ensuring their systems can reliably charge battery packs with a wide voltage range while maintaining high efficiency. The conversion of AC to DC power across varying load conditions and DC output voltages can be challenging, as discussed in (Gaxiola, Gadamsetty and Davidson 2025).

The efficiency curve for the Delta 350kW EVSE at nominal temperature of 23°C is presented in Figure 9. The Delta 350kW is highly efficient in converting AC power to DC power; hitting maximum efficiency of 96.4% at 80.14kW of average input AC power and at a load voltage of 850VDC. At lower DC voltages, like 300VDC, the efficiency peaks at 93.6% at 67.76kW of average input AC power. Efficiency decreases rapidly at loads less than 50kW due to increased relative impact of parasitic circuit conversion losses such as switching losses, transformer core losses and magnetizing currents. During post-400VDC nominal conditions experiment analysis, it was observed that recorded AC power was incorrectly computed with a lower value than expected because recorded ϕB and ϕC RMS currents were 25A to 35A less than recorded RMS current on ϕA ; recorded currents were balanced on all other tests. This discrepancy caused computed EVSE efficiency to be greater than 100% for the 400VDC nominal conditions experiment and is consequently omitted from Figure 9, but is expected to have an efficiency profile that spans from 20kW to 200kW with values that fall between the values of the 300VDC and 650VDC efficiency profiles when conducted and measured accurately. It is also noted that

the Delta 350kW EVSE has a minimum system efficiency > 92% at load levels of 50kW or higher.

There is two outlier datapoints on the Figure 9 850VDC nominal conditions efficiency profile curve at approximately 135 kW AC input power and approximately 55 kW AC input power that is attributed to a failure in one of the Delta 350KW EVSE's 14 25KW power modules. Over the course of Delta 350KW EVSE performance testing, there were four instances where a power module failed and the project team made every effort possible to run all 32 of the completed characterization tests with the EVSE in a condition capable of outputting full nameplate or evaluation power. This disturbance can also be observed in Figure 1Figure 20 and Figure 21; in all of these cases the disturbance does not interrupt the charge session or otherwise impact the conduct of the test.

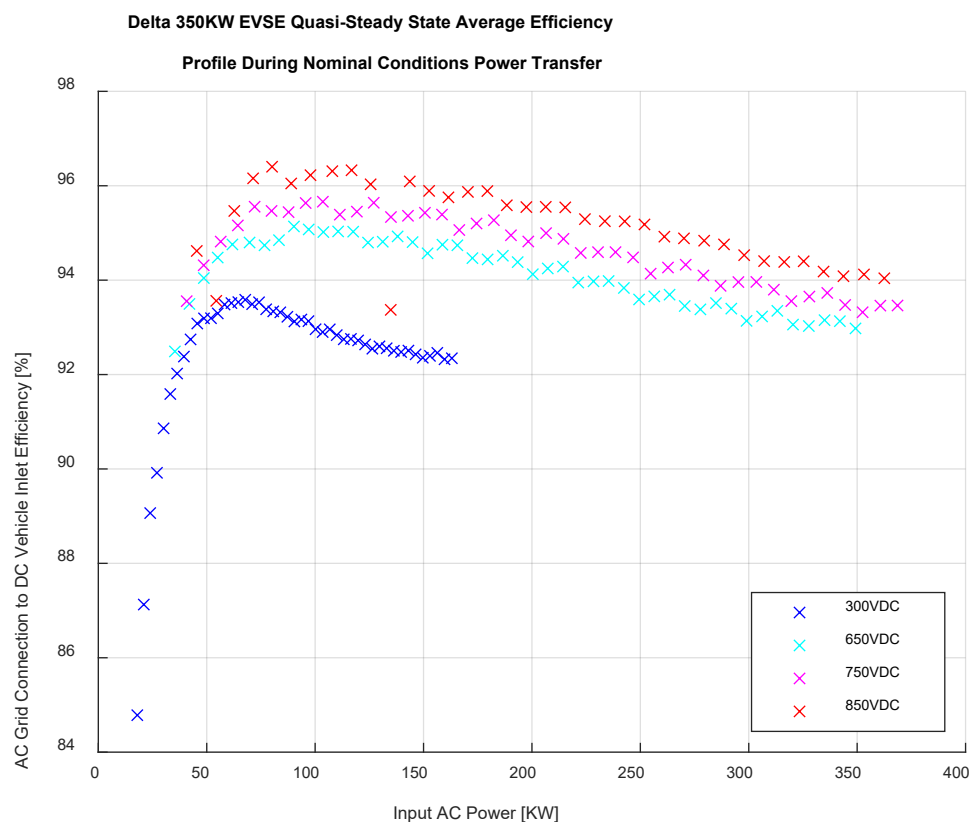


Figure 9. Delta 350kW EVSE Quasi-Steady State Average Efficiency Profile

One potential strategy to improve efficiency could be activating only the power modules required at the time for operation depending on the load. Since the Delta 350kW power cabinet contains multiple parallel power modules, activating only the necessary number of modules can help maintain operation closer to the rated power of each module would thereby improve overall efficiency system across the range of operation.

Identifying the specific causes of efficiency variations between manufacturers can be challenging as different power conversion topologies and control methods are employed. To maximize efficiency, it is essential that EVSE OEMs design converters with a deep understanding of user

needs and system characteristics so that they operate most efficiently at the power and voltage levels where they are used most frequently.

2.2.1.2.3 Power Factor Results

An EVSE that operates near-unity power factor reduces the losses incurred in the electric transmission and distribution systems, which can lead to better utilization of existing grid infrastructure and improved voltage regulation.

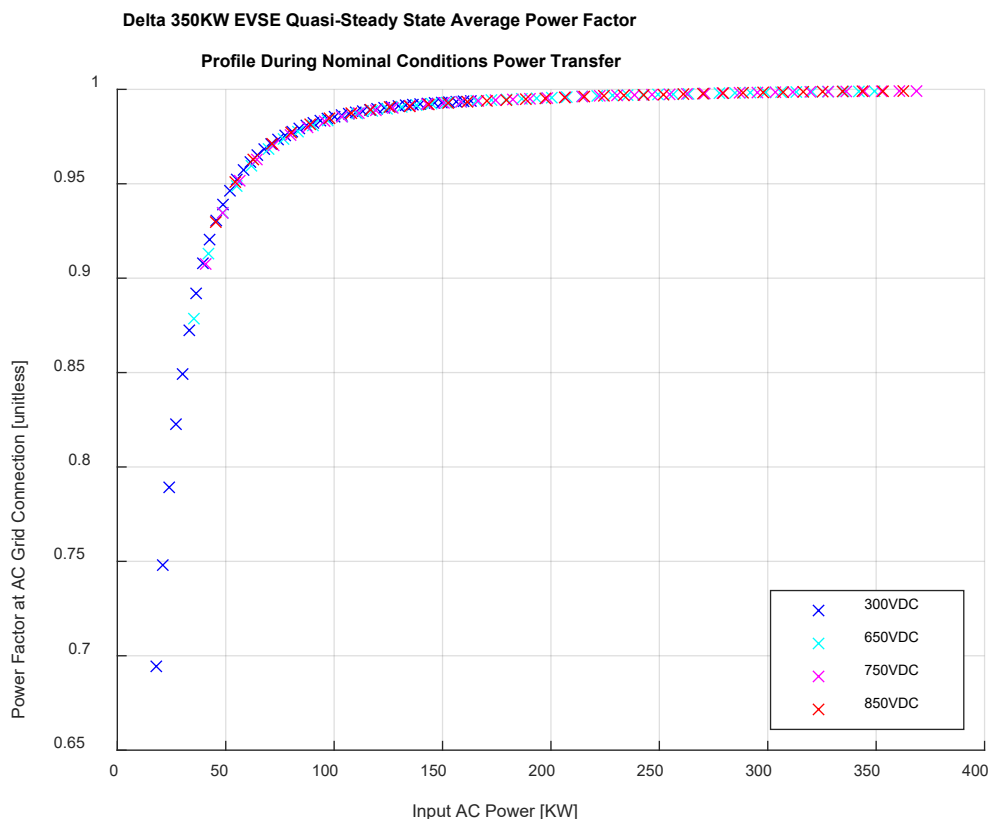


Figure 10. Delta 350kW EVSE Quasi-Steady State Average Power Factor Profile at AC Grid Connection

Figure 10 illustrates the power factor profile captured across the nominal conditions EVSE performance characterizations performed on the Delta 350kW EVSE at nominal temperature of 23°C. It is observed that Delta 350kW EVSE power factor is essentially independent of output DC voltage. Similar to Delta 350kW EVSE AC to DC conversion efficiency analysis, the 400VDC nominal conditions evaluation result is omitted from Figure 10, but is expected to have a power factor profile that spans from 20kW to 200kW with equivalent values to displayed experiment plots. EVSE power factor accounts for the impact of increased harmonics at low loads, which decreases power factor and is discussed further in the next subsection. The Delta 350kW EVSE exhibits a similar trend across the range of evaluated output voltages, with power factor exceeding 0.95 at loads ≈ 50 kW or greater and approaches unity as power load increases towards 350kW.

2.2.1.2.4 Harmonics Results

Figure 11 depicts the AC current harmonics produced by the Delta 350kW EVSE at nominal temperature of 23°C as measured at the AC grid input connection. It is observed that harmonic content of the supplied current is less than 5% of the magnitude of current in the fundamental frequency for power transfer greater than 60kW and less than 2% for power transfer greater than 150kW which is in compliance with the requirements of the SAE J2894 standard (Society of Automotive Engineers 2019). Additionally, it is observed that the harmonic distortion of the Delta 350kW EVSE is independent of output DC voltage. As with Figure 9 and Figure 10, the 400VDC nominal conditions evaluation result is omitted from Figure 11, but is expected to have a harmonic performance profile that spans from 20kW to 200kW with equivalent values to displayed experiment plots.

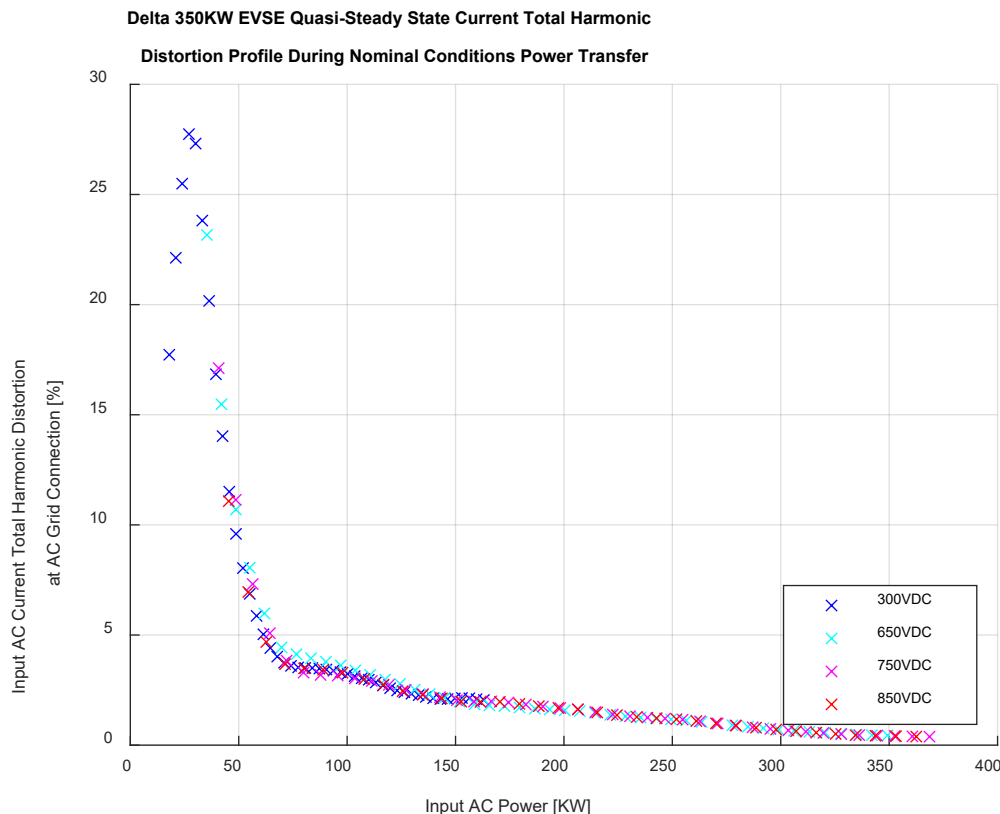


Figure 11. Delta 350kW EVSE Quasi-Steady State Average Input Current Total Harmonic Distortion at AC Grid Connection

It is observed that total harmonic distortion increases significantly at power levels below 50kW but improves as power level increases. This is due to limitations of the power electronics and zero-crossing distortion on the input current waveform. Both become less impactful at higher levels of current where the converter is designed to operate.

2.2.1.2.5 Steady State Power Consumption and Power Losses distribution

Under nominal performance characterization conditions after the four-hour soak prior to evaluation, the standby power consumption is measured. Table 4 details the real and reactive power of the Delta 350kW EVSE in a standby state. All Table 4 values are obtained from AEMC

MR527 AC/DC current probes connected to a Yokogawa WT1800 power quality meter; the sum of squares relationship between real power, reactive power and apparent power does not hold up in standby mode with contactors open because of the small current signal magnitude, increased impact of noise and non-linearity of high current measurement sensor response at the extremes of their operation range. It is observed that the Delta 350kW EVSE has a sleep state and an active standby state when no power transfer is occurring: in the sleep state, no vehicle is connected, main contactors are open and the EVSE is idle. In active standby state, a vehicle may or may not be connected, main contactors are shut and power is not transferred to the EV if connected. After completing a charge session, the Delta 350kW EVSE remains in the active standby state with contactors closed for approximately three minutes before opening contactors and returning to the sleep state. As with other nominal conditions experiment findings, the 400VDC nominal conditions experiment result is omitted from Table 4, but is expected to have results that correlate well with the findings from the other nominal conditions experiments.

Table 4. Standby Power Consumption (No Power Transfer to EV)

EVSE	Average Real Power (W)	Average Reactive Power (VAR)	Average Apparent Power (VA)
Delta 350kW (main contactors open)	≈17.6	≈116.3	≈214.8
Delta 350kW (main contactors shut)	≈607.3	≈-19437.8	≈19447.7

Figure 12 illustrates the EVSE losses and auxiliary loads for the Delta hardware at a nominal temperature of 23°C at 650VDC, under quasi-steady-state evaluation conditions. EVSE losses and loads are categorized into three main categories:

- Charging connector losses, which primarily consists of resistive losses that occur along the length of the charging connector cable.
- Auxiliary loads, which include 120VAC secondary supply used to energize the auxiliary loads such as cooling systems, lighting for EVSE operator, the display screen that shows the status of the charging process, etc.
- AC to DC conversion losses, which primarily occurs in power cabinets and may include switching, conduction and magnetic losses during the energy conversation process.

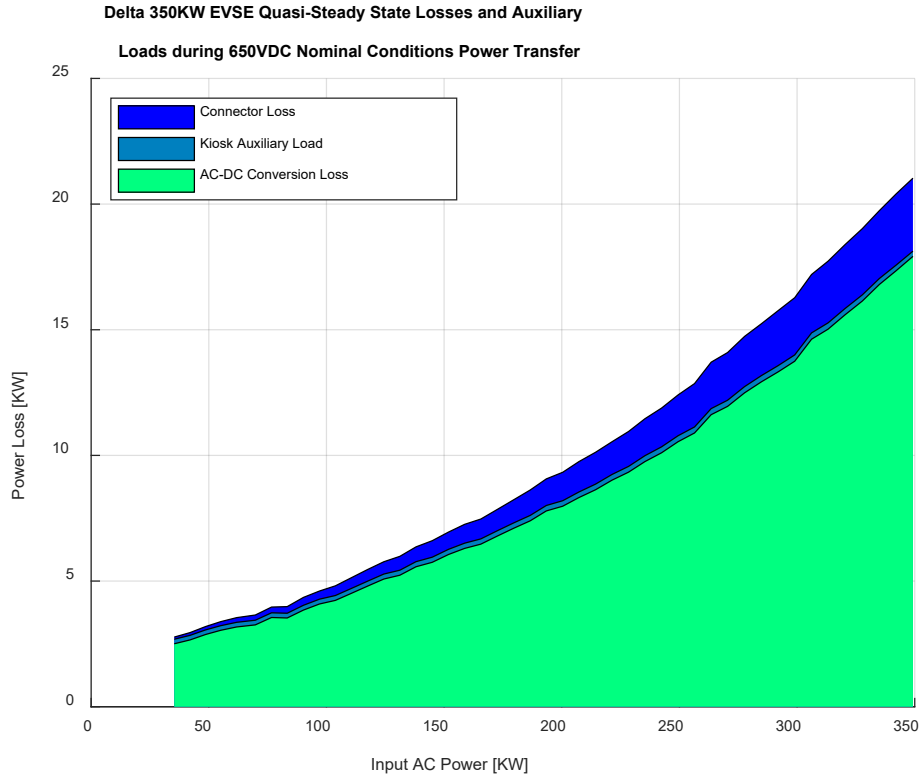


Figure 12. Delta 350kW EVSE Losses and Auxiliary Loads During 650VDC Power Transfer

The most significant losses are observed in the AC to DC conversion stage when compared to the losses from the other two contributors. It is observed that the combined charging cable and auxiliary losses range from $\approx 0.5\text{kW}$ to $\approx 3\text{kW}$ over the operating range whereas AC to DC conversion ranges from $\approx 2.5\text{kW}$ to $\approx 18\text{kW}$ of additional loss.

2.2.1.2.6 Phase Imbalance Results

EVSE phase-to-phase current imbalance at the AC input connections is quantified from quasi-steady-state evaluations at nominal conditions. As shown in Table 5, the average phase-to-phase current imbalance is 0.70% for the Delta 350kW EVSE. It was observed that this EVSE exhibits a trend of decreasing phase imbalance as the total RMS current increases, suggesting that the system becomes more balanced at higher loads.

Table 5. Delta 350kW EVSE Phase-To-Phase Current Imbalance During Quasi-Steady State Power Transfer

EVSE	Maximum Imbalance	Average Imbalance
Delta 350kW	1.70%	0.70%

As with other nominal conditions experiment findings, the 400VDC nominal conditions evaluation result is omitted from Table 5, but is expected to have results that correlate well with the findings from the other nominal conditions experiments.

2.2.1.2.7 Phase Imbalance Results

Ground current contribution from the Delta 350kW EVSE was instrumented for all EVSE performance characterization tests; selected nominal conditions power transfer test ground current contribution profiles are depicted in Figure 13. It is observed that maximum ground current is at full EVSE load decreases as vehicle voltage increases and the rate that the ground current contribution increases is roughly linear with EVSE load. The maximum recorded ground current measurement was ≈ 2 AAC during the 650VDC nominal conditions power transfer evaluation.

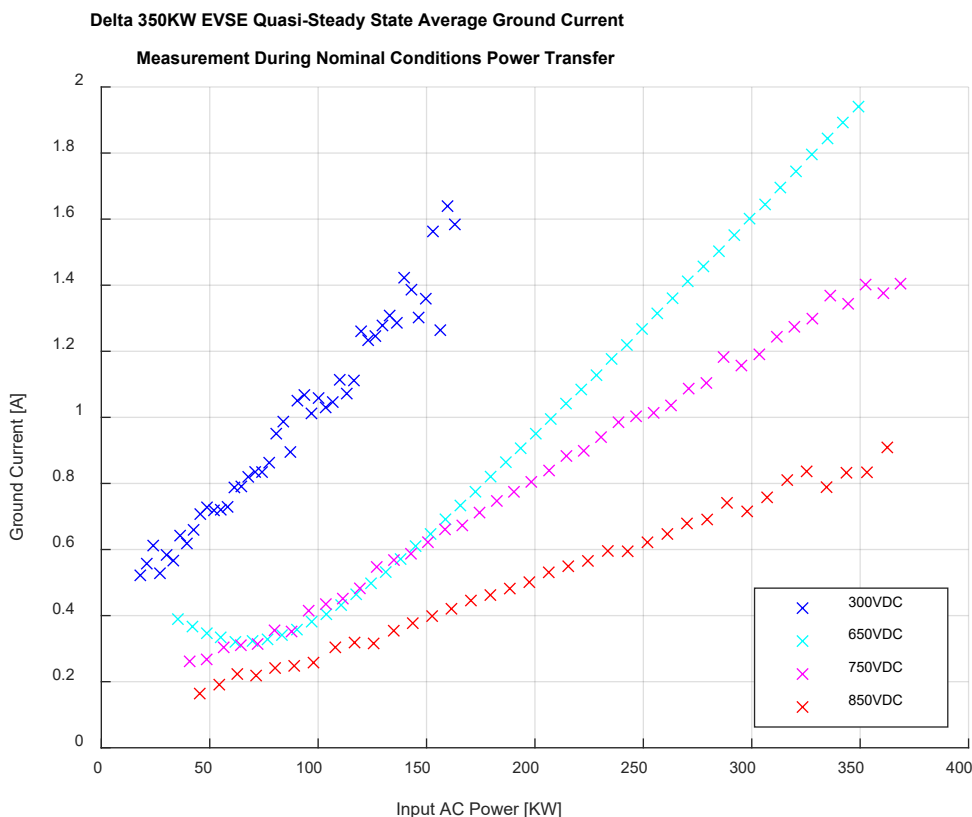


Figure 13. Delta 350kW EVSE Average Ground Current Contribution Profile During Nominal Conditions Power Transfer

2.2.1.2.8 Power Sharing Strategy between Cabinets

The Delta 350kW EVSE consists of a single AC-DC power conversion cabinet; analysis of the cabinet power sharing strategy is not applicable for this EVSE. However, unlike the EVSEs evaluated in *EVSE Characterization, A Next-Gen Profiles Project Report* (Carlson and Onar 2023) and *EVs@Scale Next-Gen Profiles -EVSE Characterization 2024* (Kogalur, et al. 2025), the Delta 350kW EVSE is capable of sharing its charging capacity between two EVs charging simultaneously. See Section 2.2.5 EVSE Characterization at Off-Nominal for analysis of Delta 350kW EVSE multi-port/multi-session power sharing strategy.

2.2.2 EVSE Characterization at Off-Nominal Grid Input Conditions

2.2.2.1 Procedure

EVSE off-nominal AC grid input performance characterization is conducted using an AC grid simulator to emulate the AC grid conditions and transients listed in Table 6, Table 7, and Table 8. These conditions include voltage deviation, frequency deviation, and voltage harmonics injection. The voltage deviation and frequency deviation experiment conditions include both sag and swell conditions. Each of the evaluation conditions is characterized independently; no concurrent off-nominal conditions are evaluated. Each off-nominal AC grid input experiment condition will be conducted at the off-nominal DC current and DC voltage power transfer experiment conditions detailed in Table 1.

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

- The EVSE will soak at the ambient temperature prescribed for the experiment conditions for a minimum of 4 hours prior to commencing evaluation.
- 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 evaluation sequence.
- The charge session will be initiated at nominal AC input grid conditions.
- Each evaluation point parameter is collected for the list of Table 2 off-nominal condition experiments.
 - Acceptable tolerance for the power transfer prior to entering the off-nominal conditions is +/- 0.2 A and +/-1 V.

The off-nominal condition experiments will be performed in accordance with Table 6 for AC voltage deviation evaluation, Table 7 for AC frequency deviation evaluation, and Table 8 for AC voltage harmonics injection evaluation.

Table 6. 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 7. EVSE Frequency Deviation Test

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 8. EVSE Voltage Harmonics Injection Test

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 points of the evaluation, or the operator may end the charge session and begin a new charge session as necessary between each off-nominal experiment.

2.2.2.2 Results

2.2.2.2.1 AC Voltage Deviation

Per SAE J2894 and ANSI C84, the AC input voltage deviation experiment reduces phase voltage from the nominal value of 277VAC (480VAC line voltage) in steps down to phase voltage of 248VAC (430VAC line voltage) and then steps up to phase voltage of 303VAC (525VAC line voltage) and returns to the nominal phase voltage value of 277VAC (480VAC line voltage) over an approximate five-minute evaluation period. Under all AC voltage deviation experiment conditions, the Delta power transfer remains uninterrupted and the DC current remains stable throughout all transitions without observable change in typical DC current ripple, though quantifying the magnitude change of DC current ripple is challenging as the 3-second hold duration of the various experiment voltages can be shorter than the DC ripple wave period. Figure 14 depicts results of the 400VDC & 500ADC off-nominal grid input voltage variation experiment.

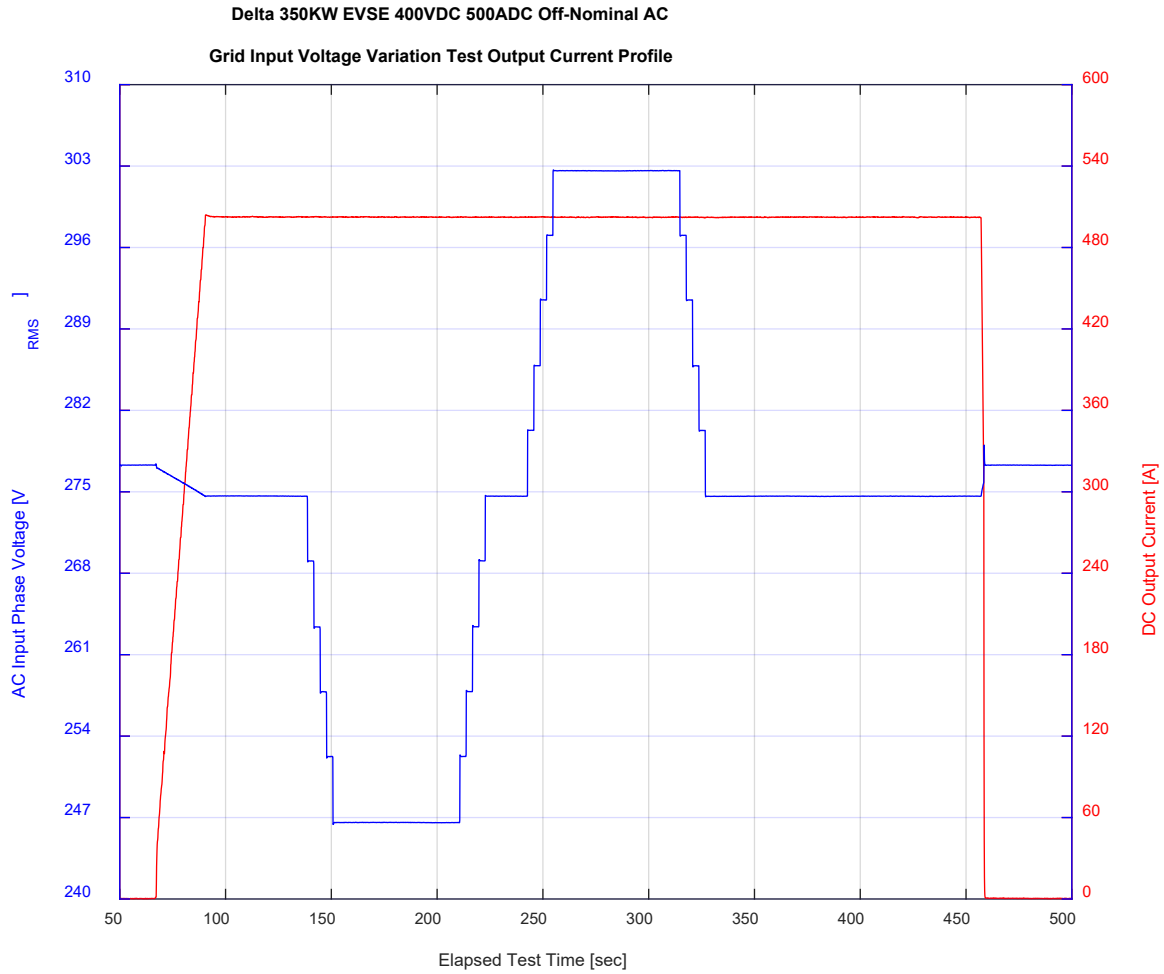


Figure 14. Delta 350kW EVSE 400VDC 500ADC Off-Nominal AC Grid Input Voltage Variation Experiment Profile

It is observed that the power factor varies inversely relative to AC input voltage, though the effect is relatively small. For example, during the 400VDC 150ADC experiment, the power factor under load is 0.963 with swings up to 0.977 and down to 0.945 as shown in Figure 15. The effect of grid voltage variation on power factor is largest at low EVSE load; the 400VDC 150ADC experiment was observed to have the largest swings in power factor of the four off-nominal AC grid input voltage variation evaluations performed per Table 1.

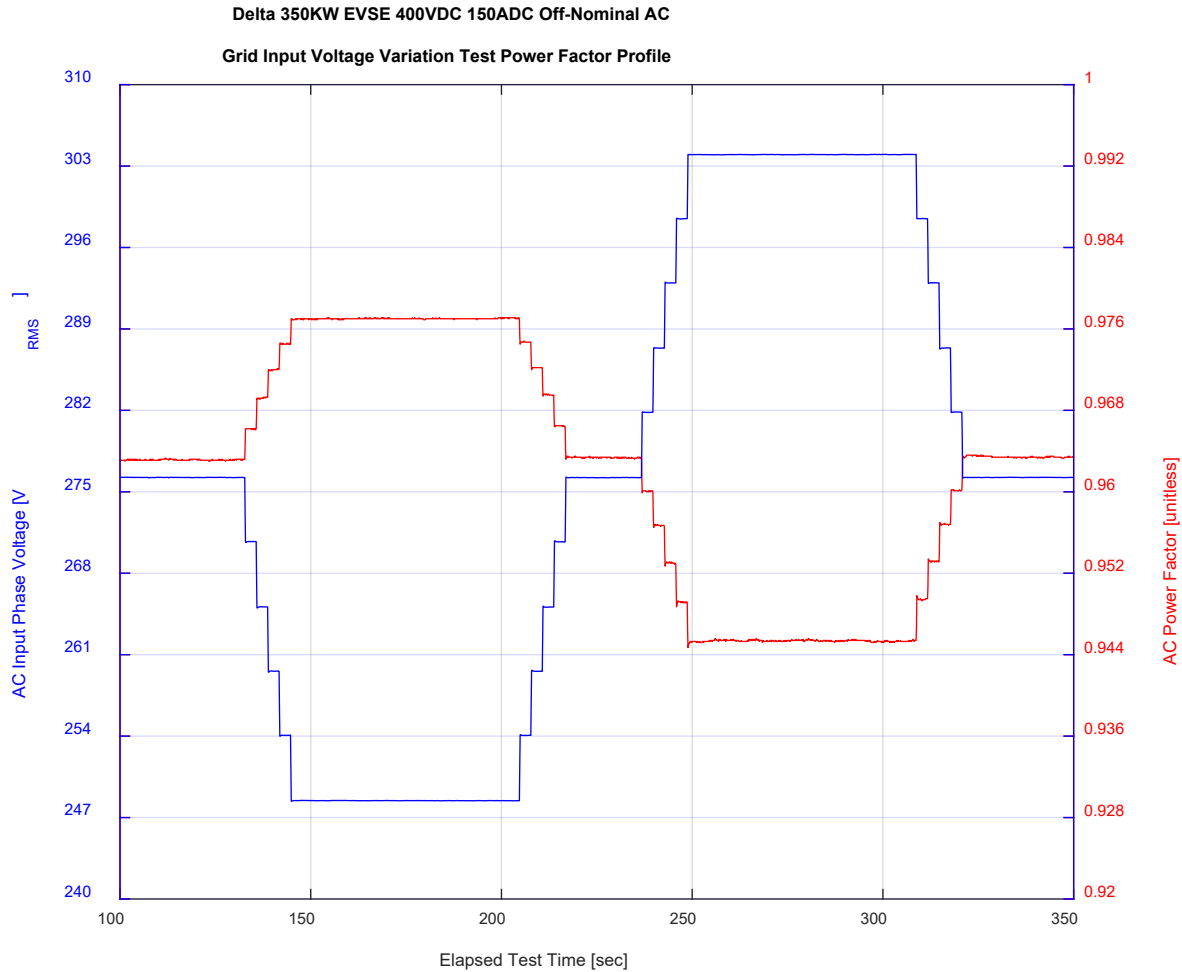


Figure 15. Delta 350kW EVSE 400VDC 150ADC Off-Nominal AC Grid Input Voltage Variation Experiment Power Factor Profile

2.2.2.2.2 AC Frequency Deviation

The off-nominal AC input frequency deviation experiment steps frequency down from 60Hz nominal to 51.8Hz, then steps up to 61.2Hz and returns back to 60Hz over an approximate one-minute evaluation period. Under all AC frequency deviation evaluation conditions, the Delta power transfer remains uninterrupted, and the DC current remains stable throughout all transitions without observable change in system output current ripple. Quantifying the magnitude change of DC current ripple is challenging as the 3-second hold duration of the various experiment frequencies can be shorter than the DC ripple wave period. Figure 16 depicts results of the 850VDC & 500ADC off-nominal grid input voltage variation experiment. It is observed that the Delta 350kW EVSE current output response is independent to frequency variation at all Table 1 off-nominal grid frequency variation evaluations.

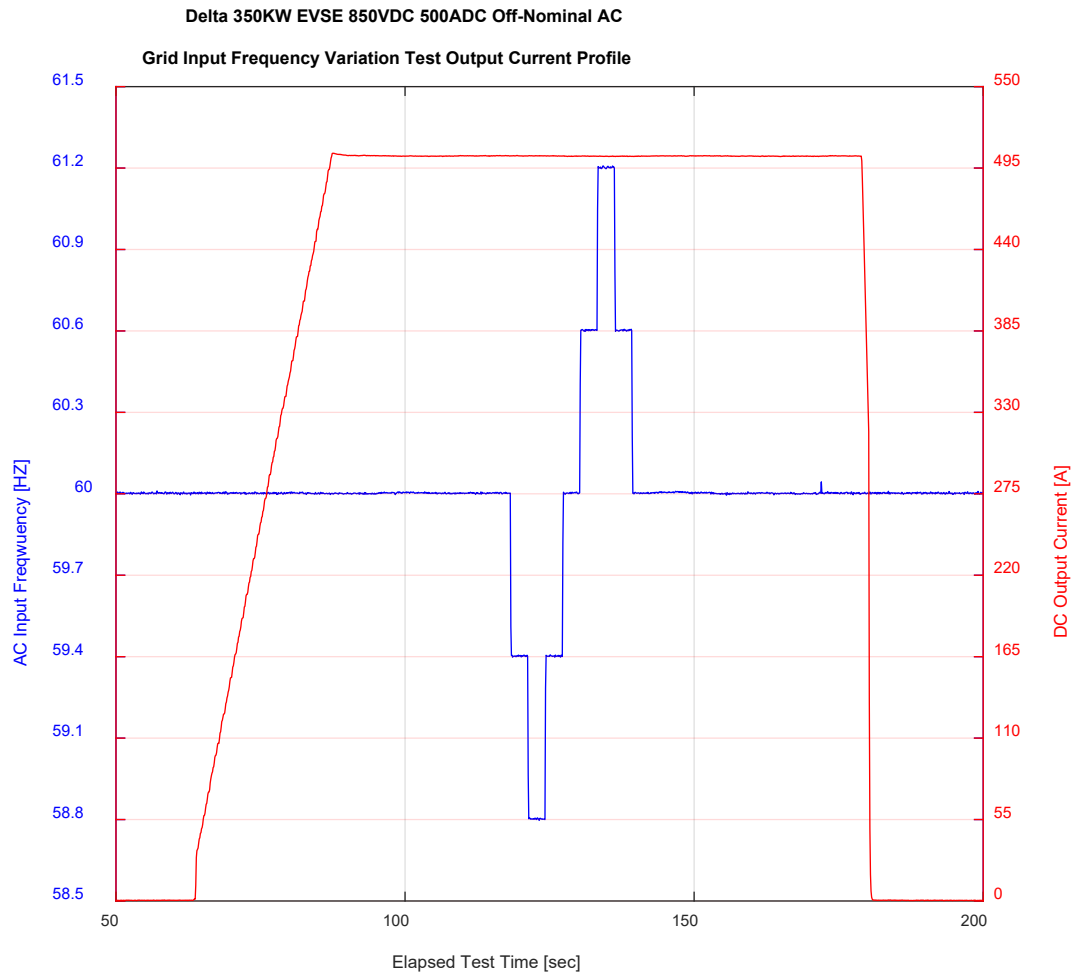


Figure 16. Delta 350kW EVSE 850VDC 500ADC Off-Nominal AC Grid Input Frequency Variation Experiment Profile

2.2.2.2.3 AC Harmonics Injection

As with all other EVSE performance characterizations, the off-nominal grid harmonics evaluation is performed by lining up the EVSE to a grid simulator that provides input power in the form of a pure 277 VAC line-to-neutral (phase voltage) sine wave where all three phases are 120 degrees out of phase with each other as an initial condition. The vehicle emulator is then set up in one of the off-nominal evaluation configurations listed in Table 1 and experiment recording is started. After the EVSE is plugged in to the vehicle emulator, the charge session is allowed to run for a minimum of one minute then the grid simulator is set to input a distorted sine wave voltage with 5% THD for 10 seconds. After the harmonics injection transient, the grid simulator resumes providing clean power with the pure 277 VAC 60 Hz 3-phase sine wave.

Figure 17 depicts the 400VDC & 150ADC off-nominal grid input harmonics variation evaluation inputs and outputs. It is observed that the Delta 350kW EVSE exhibited no change in its output while being served voltage with harmonic content: power transfer remained uninterrupted and there were no discernible changes in VDC or IDC or other recorded output parameters during the transient under any of the Table 1 evaluation conditions, except for the 850VDC & 500ADC

experiment. During the 850VDC & 500ADC grid input harmonics experiment, the application of voltage with harmonic content did not change recorded VDC but did cause the EVSE to reduce EV charging current from $\approx 410\text{ADC}$ (full-power current) to 380ADC; a value below the EV-requested target setpoint. Completion of the voltage harmonic transient caused a momentary transient where EV charging current was reduced from $\approx 380\text{ADC}$ to $\approx 60\text{ADC}$, after which charging continued at 380ADC: the EVSE did not supply full-power current of 410ADC for the remainder of the charge session. The 850VDC & 500ADC off-nominal grid input harmonics variation experiment was performed twice to ensure repeatability of result, but the cause of the captured experiment result cannot be conclusively determined without additional detailed engineering investigation which is outside of the scope of work of the NextGen Profiles project.

As with other evaluations, it is observed that the amount of AC input current total harmonic distortion increases with increasing load; the 400VDC & 150ADC experiment has maximum AC input current distortion $\approx 40\%$ while the 850VDC & 500ADC experiment has maximum distortion $\approx 5\%$. Figure 17 shows that AC input current increases slightly $\approx 4\%$ at 400VDC and $\approx 2\%$ at 850VDC while the voltage harmonic transient is applied to EVSE.

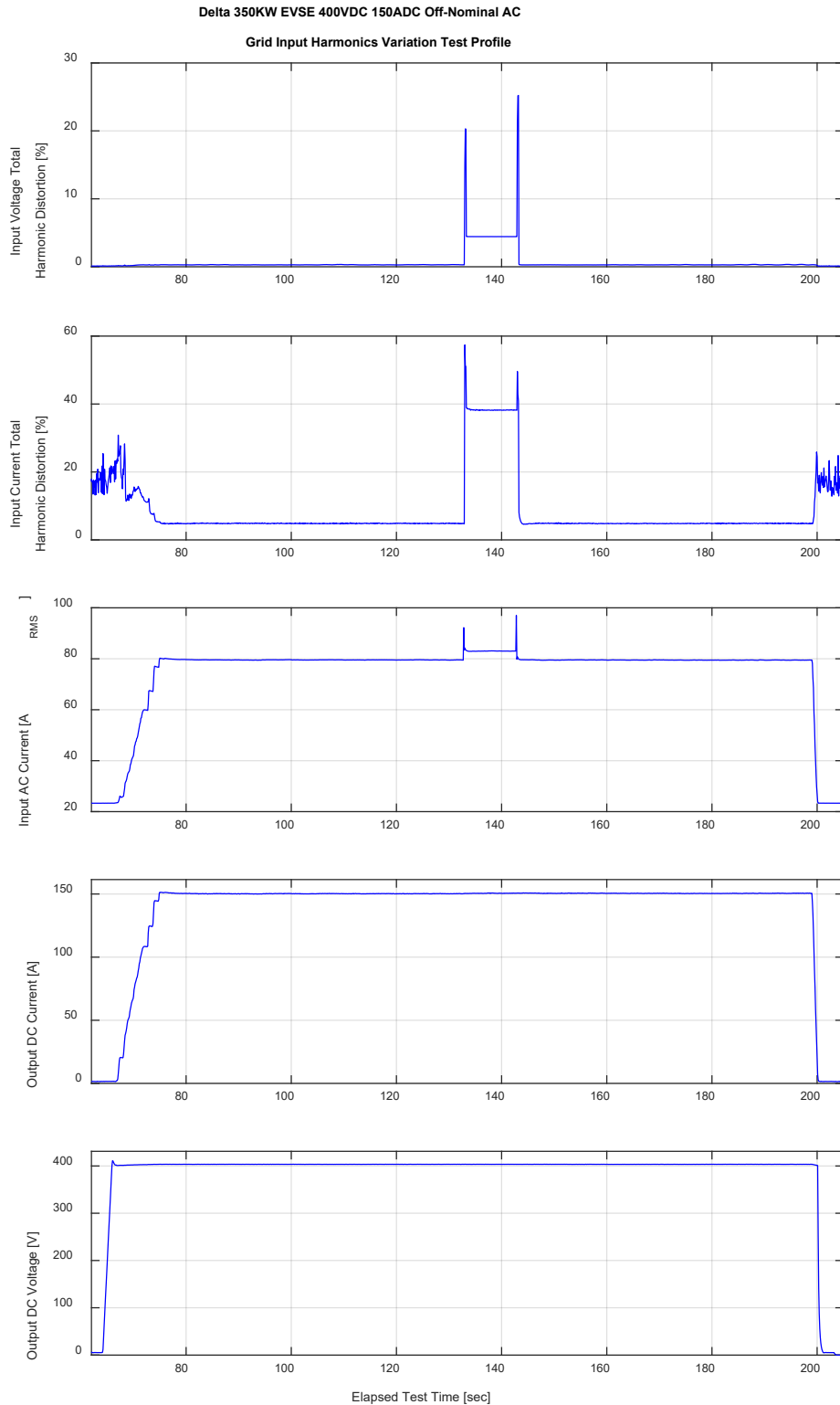


Figure 17. Delta 350kW EVSE AC Current and Voltage During Off-Nominal Harmonics Injection Experiment

2.2.3 EVSE Characterization at Off-Nominal Ambient Temperature Conditions

Off-nominal ambient temperature performance characterizations of the Delta 350kW EVSE were not performed due to limitations of supporting laboratory equipment. Thermal performance of the Delta 350kW EVSE is discussed in Section 2.2.5 EVSE Characterization at Off-Nominal Thermal Control System Test Conditions. Quantification of the amount of localized heating, effect of placement of EVSE cabinets on EVSE performance and EVSE performance at off-nominal ambient temperatures are several areas of inquiry not examined in this report worthy of further study.

2.2.4 EVSE Characterization at Off-Nominal Smart Charge Management Conditions

2.2.4.1 Procedure

Off-nominal smart charge management response evaluations are conducted using OCPP 1.6j for the current and voltage experiment conditions of Table 1. EVSE Power Transfer Characterization Test Conditions. The smart charge management curtailment requests include *TxProfile*, *MaxChargePoint* and *TxDefaultProfile* which are used for NextGen Profiles SCM evaluations to send curtailment commands of 54kW or 65A for as many as three curtailment profiles for each of the four off-nominal Table 1 DC power transfer evaluation conditions. Table 9 summarizes the off-nominal smart charge management experiments performed on the Delta 350kW EVSE:

Table 9. Delta Smart Charge Management Test Conditions

Power Transfer Conditions	Curtailment Levels Tested	Smart Charge Management Commands
400 VDC 150 ADC	65 A	<i>TxProfile</i> , <i>MaxChargePoint</i> , <i>TxDefaultProfile</i>
400 VDC 500 ADC	65 A	<i>TxProfile</i> , <i>MaxChargePoint</i> , <i>TxDefaultProfile</i>
850 VDC 150 ADC	65 A	<i>TxProfile</i> , <i>MaxChargePoint</i> , <i>TxDefaultProfile</i>
850 VDC 500 ADC	65 A	<i>TxProfile</i> , <i>MaxChargePoint</i> , <i>TxDefaultProfile</i>

The Open Charge Alliance's OCPP open communication protocol (Open Charge Alliance 2025) defines current curtailment requests as the input to the EVSE (i.e., AC current) and power curtailment requests are manufacturer-specific at either the input or the output of the EVSE (i.e., AC input power or DC output power). Features of the OCPP protocol are implemented differently based on the manufacturer and specific EVSE under consideration and may not conform to strict interpretations of OCPP requirements. The NextGen Profiles evaluation procedures and requirements for a smart charge management characterization experiment are as follows:

- Record the vehicle emulator make/model, EVSE make/model /firmware version, ambient temperature, day/time, OCPP server version, etc.
- Begin a charge session and operate the EVSE at the Table 1 off-nominal DC voltage and DC current experiment conditions for a minimum of 60 seconds.
- Transmit the Table 2 smart charging profile request via OCPP 1.6j or newer (e.g., *TxProfile* 65A current request):

- Note the system (e.g., local controller, cloud system) and specific signal request for SCM system alternatives that do not utilize OCPP.
- After curtailing system operation for a minimum of two minutes, use the *ClearChargingProfile* command to restore normal EVSE operation. Once the charge profile request is accepted, allow EVSE to reach steady-state operation for a minimum of two minutes before completing the off-nominal Table 2 smart charge evaluation and ending data collection or continuing to the next experiment.
- Repeat this experiment sequence for each DC current and DC voltage condition listed in Table 1 for each of the smart energy management curtailment requests listed in Table 2.

2.2.4.2 Results

EVSE response to curtailment commands vary widely across industry as implementation of the OCPP standard varies with manufacturer and EVSE model. In response to an OCPP SCM command, EVSEs can have one or multiple options available for curtailment: limit AC input current, DC output current, AC input power and/or DC output power. The Delta 350kW EVSE has an OCPP implementation that is configured to limit DC output current to 65ADC. Table 10 lists the bias between measured and commanded current and current ramp-down overshoot in response to SCM commands.

Table 10. Delta 350kW EVSE OCPP Power Curtailment Steady-State Characteristics

Curtailment Command	DC Load Voltage [V]	DC Load Current [A]	Curtailment Request [A]	Average Steady-State Measured Current [A]	Measured-Request Delta [%]	Ramp-Down Current Overshoot [A]
MaxChargePoint	400	150	65	65.019	0.029	5.738
MaxChargePoint	400	500	65	66.144	1.760	22.950
MaxChargePoint	850	150	65	64.992	-0.012	3.421
MaxChargePoint	850	500	65	66.345	2.069	16.190
TxDefaultProfile	400	150	65	65.054	0.083%	5.835
TxDefaultProfile	400	500	65	66.042	1.603%	23.664
TxDefaultProfile	850	150	65	67.135	3.285%	5.750
TxDefaultProfile	850	500	65	66.229	1.890%	15.635

The Delta 350kW EVSE does not implement the *TxProfile* command from the OCPP standard; the EVSE was not responsive to *TxProfile* commands sent. Accordingly, the Table 1 and Table 2 *TxProfile* experiments were not performed and results are not reported in Table 10. All other curtailment requests successfully result in power transfer reduction soon after the request is initiated, and the power transfer resumes at the previously requested level soon after the curtailment request is cleared. The *ClearChargingProfile* request message is used to end the curtailment.

The latency of the Delta 350kW EVSE to respond to a Smart Charge Management command is ≈ 1.441 seconds on average, with a minimum of ≈ 1.149 seconds in a best-case scenario

laboratory network experiment condition. For the range of evaluation cases and conditions, the average ramp rates vary considerably from -1517.58ADC/sec on the 400VDC & 500ADC *TxProfile* response experiment to +659.52ADC/sec on the 400VDC & 500ADC *MaxChargePoint* response experiment. It is observed that the evaluations with the largest magnitude ramp rates were the 400VDC & 500ADC experiments, presumably because those evaluations are conducted with the highest vehicle charging current to start and end the experiment. It is additionally observed that the Delta 350kW EVSE is capable of exceeding the minimum limit of -200A/sec ramp down and maximum limit of +20A/sec ramp up rate limits specified in the SAE J1772 standard (Society of Automotive Engineers 2025). This can have a significant effect in aggregate on grid distribution feeders. As the curtailment is caused by an OCPP command and not a change in EV requested charging current, the result appears to be independent (but limited by) the charging EV's current request. Additional effort and evaluation is needed to quantify standards compliance across industry.

Table 11. Delta 350kW EVSE OCPP Power Curtailment Performance Metrics

Curtailment Command	DC Load Voltage [V]	DC Load Current [A]	Latency from Command to Power Ramp [sec]	Ramp-Down Rate [A/sec]	Ramp-Up Rate [A/sec]
MaxChargePoint	400	150	1.451	-224.578	21.697
MaxChargePoint	400	500	1.566	-1138.394	659.522
MaxChargePoint	850	150	1.794	-440.181	19.396
MaxChargePoint	850	500	1.149	-882.998	600.767
TxDefaultProfile	400	150	1.507	-229.520	20.413
TxDefaultProfile	400	500	1.462	-1517.582	643.409
TxDefaultProfile	850	150	1.389	-437.706	21.513
TxDefaultProfile	850	500	1.213	-887.255	598.750

2.2.5 EVSE Characterization at Off-Nominal Thermal Control System Test Conditions

2.2.5.1 Procedure

During NGP performance characterizations, EVSEs undergo thermal control system evaluation where a series of high current and high-power charging sessions are conducted back-to-back with a nominal rest time between charge events. The purpose of this test is to characterize the performance of the EVSE thermal management system at a nominal 23°C ±2°C ambient temperature. The NextGen Profiles evaluation procedures and requirements for the thermal control system characterization experiment are as follows:

- Prepare EVSE initial conditions; soak the HPC EVSE at nominal temperature for > 4 hours
- Record the charger make/model /firmware version, ambient temperature, day/time, etc.
- Begin data collection 60 seconds before plug-in
- Follow evaluation sequence from Table 12. Ensure to unplug the charger during the stop charge session and plug it back in to begin the next charging session

- Continue to collect data for 5 minutes after completion of charge event or until auxiliary power returns to standby power level
- Stop data collection 60 seconds after the end of the evaluation.

Table 12. EVSE Thermal Control Testing Sequence

Step #	Duration	Test Condition Category	DC Current Conditions	DC Voltage Test Conditions	Tolerance
1	< 2 min.	Plug-in and start charge session	0A	0V	--
2	10 min.	Steady State Power transfer (maximum rated power *)	Maximum available Current *	750V	± 2°C
3	< 5 min.	Stop Charge Session	0A	0V	--
4	10 min.	Steady State Power transfer (maximum rated power *)	Maximum available Current *	750V	± 2°C
5	< 5 min.	Stop Charge Session	0A **	0V	--
6	10 min.	Steady State Power transfer (maximum rated power *)	Maximum available Current *	750V	± 2°C
7	5 min.	Stop Charge Session	0A	0V	--
Note * - Operate at highest current possible, at the experiment voltage specified, up to EVSE full power capability					

Measurements from Table 2 are recorded at a sample rate of 10 Hz continuous measurement. For a discussion of EVSE thermal performance, it should be noted that the EVSE kiosk and EVSE power cabinet were installed and operated in an indoor laboratory space in locations compliant with the Delta 350kW EVSE manufacturer's installation manual, separated by approximately 30 feet. Other power conversion hardware was operated near the power cabinet during NextGen Profiles Delta 350kW EVSE performance characterization which exhausted heat to the surrounding air that likely was entered the power cabinet intake and raised power cabinet temperatures, not unlike a separate EVSE cabinet operating nearby.

2.2.5.2 Results

Effective thermal management of charging conductors and cables is important for ensuring high performance and efficient vehicle charging with charging connectors that are safe, cost effective and have minimal maintenance requirements, cost and long useful lifespans. Actively cooled cables are necessary to balance the size, weight and maneuverability of the charging cable for all users with the high standard of performance set by liquid-fueled vehicles that is expected by the public.

Figure 18 depicts the chronological current and DUT temperature profiles recorded T-type thermocouples using a Yokogawa DL850 scopecorder during the Delta 350kW EVSE thermal control system experiment. It is observed that the Delta 350kW EVSE capably handled the

sequence of maximum power charge sessions with no curtailment of vehicle charging power. Over the course of the experiment sequence, it is noted that a large excursion in ambient temperature occurs during every charge session; this is attributed to the fact that the ambient temperature sensor was located at eye level outside and close enough to the EVSE kiosk such that hot air exiting the kiosk was indirectly exhausted on the ambient temperature sensor. This effect was not noted on other EVSE performance characterizations performed on the Delta 350kW EVSE or other EVSEs evaluated and documented in prior NGP reports. It is noted that in future evaluations, a true reading of the ambient temperature will require that the sensor should be located further from the EVSE kiosk or EVSE power cabinets, although such a location will not capture the effect of localized ambient air heating caused by EVSE operation. The ambient temperature over the sequence of the three maximum power charge sessions is as follows: before and after the first charge session ambient temperature $\approx 22^{\circ}\text{C}$, after the second charge session ambient temperature $\approx 23^{\circ}\text{C}$ and after the third charge session ambient temperature $\approx 24^{\circ}\text{C}$. Quantification of the amount of localized heating, effect of placement of EVSE cabinets on EVSE performance and EVSE performance at off-nominal ambient temperatures are several areas of inquiry not examined in this report worthy of further study.

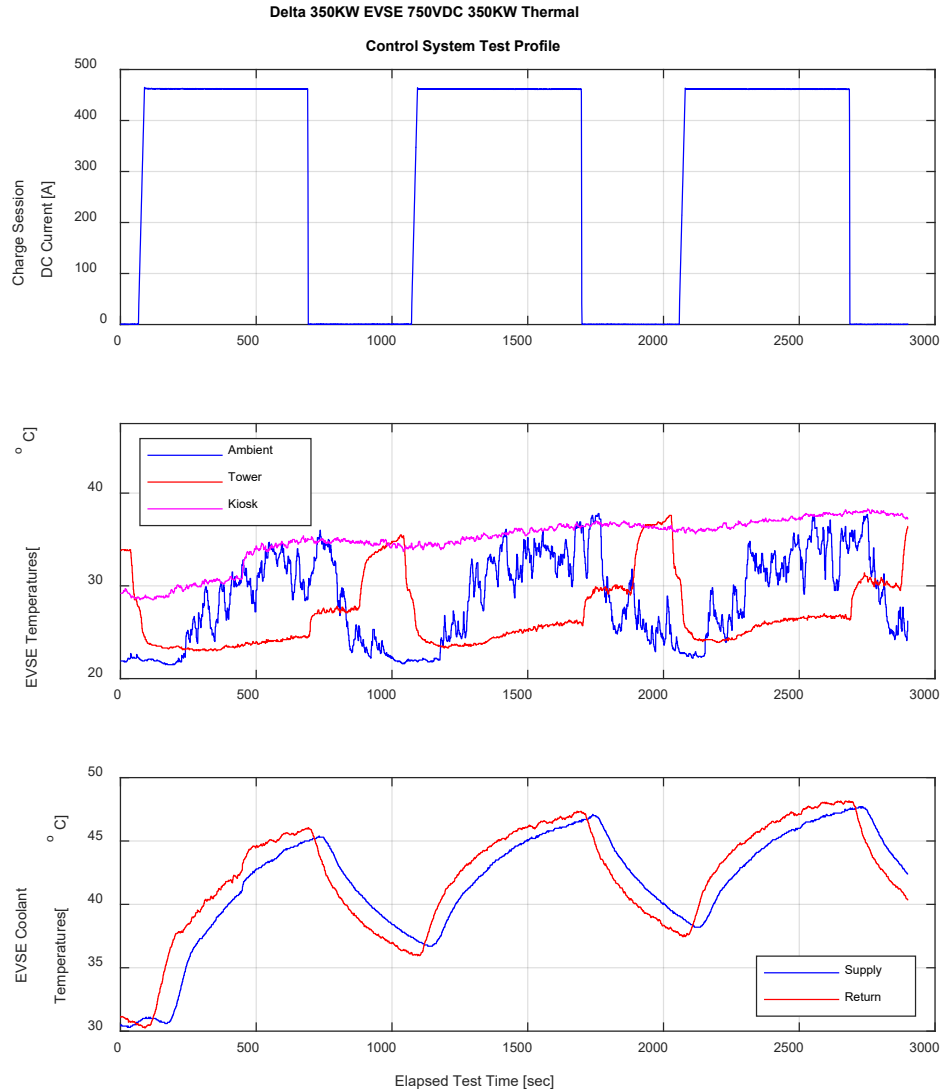


Figure 18. Delta 350kW EVSE Thermal Control Systems Test Instrumented Temperature Profile

It is additionally observed that EVSE cabinet temperatures unintuitively achieve their minimum values during the charge session and then increase significantly while the EVSE is idle. This is attributed to the fact that the cabinet temperature sensor was placed in the EVSE power cabinet in the intake plenum for accessibility reasons: while the EVSE is operating, the temperature sensed by the EVSE cabinet is essentially ambient temperature and when the charge session terminates, the EVSE power cabinet fans turn off while the EVSE is idle, causing cabinet power electronics latent heat to conduct and convect back to the cabinet temperature sensor. Although the trend for EVSE kiosk temperature increases over the course of the three subsequent charge sessions, kiosk temperature equalizes without large excursions once a temperature $\approx 35^{\circ}\text{C}$ is reached. EVSE coolant supply and return temperatures were also monitored with T-type thermocouples that were installed on metallic coolant piping installed inside the EVSE kiosk and exhibit the delay in response to a step change current expected from instrumentation of this type.

Technical limitations prevented the NGP team from duplicating the Delta 350kW EVSE's own thermal sensor temperature signals and logging values with a high-fidelity/high-precision data logger. Instead, with the assistance of corporate partners, the team exported the Delta 350kW EVSE's temperature logs for the Thermal Control System experiment and overlaid the results with parameters that were logged with high-fidelity/high-precision sensors in Figure 19. From top to bottom, panel 1 in Figure 19 depicts DC charging current, as measured by both the DL850 with AEMC MR527 current transformer and built-in EVSE DC current sensing, which proves the goodness of fit of logged EVSE values. Panel 2 depicts ambient temperature as measured by DL850 with T-type thermocouple and built-in EVSE ambient temperature sensor. It is noted that the EVSE ambient temperature sensor is not sensitive to the temperature excursions caused by hot kiosk air exhaust that the DL850 thermocouple is. It is additionally noted that in all panels the Delta 350kW EVSE only logs performance parameters during an active charge session and that temperature parameters logged by the EVSE have reduced fidelity and precision when compared to DL850-recorded values. Panel 3 depicts built-in EVSE kiosk CCS connector pin temperatures and CCB emulated vehicle inlet temperatures as measured by the DRTS. As expected, it is observed that the liquid-cooled CCS connector terminals heat up more slowly and cool down more quickly than the air-cooled CCS inlet terminals. Panel 4 depicts built-in EVSE kiosk CCS cable lug temperatures where high-current liquid-cooled CCS conductor lugs land. Panel 5 depicts built-in EVSE kiosk busbar temperatures where DC field wiring conductor lugs land. Panel 6 depicts EVSE coolant supply and return temperatures as measured by T-type thermocouples attached to metallic coolant piping and by built-in EVSE temperature sensors. The temperature difference between EVSE-reported coolant temperature values and those reported by the high-fidelity/high-precision data logger is likely explained due to sensor type and placement; the EVSE-recorded coolant temperatures likely exhibit superior accuracy.

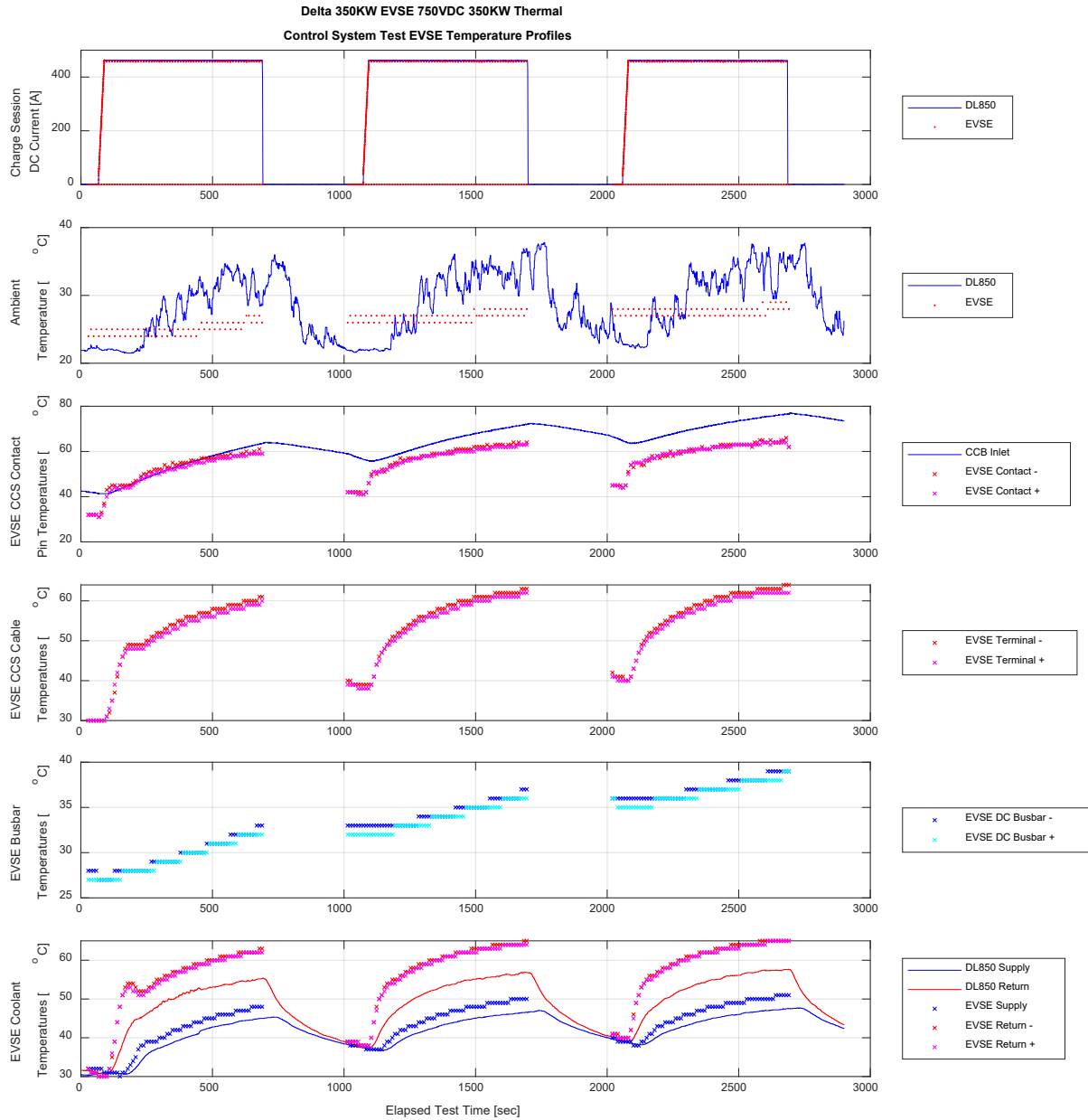


Figure 19. Delta 350kW EVSE Quasi-Steady State Average Efficiency Profile

2.2.6 EVSE Characterization at Off-Nominal Multi-Port Simultaneous Charging Conditions

2.2.6.1 Procedure

The Delta 350kW EVSE has two CCS connectors which are labeled connectors A and B. The EVSE can charge a single EV using connector A or B or two EVs simultaneously using connectors A and B, which splits the maximum 350kW power limit. Testing the simultaneous charging ability of the Delta 350kW EVSE involves setting up two CCBs vehicle simulators to charge under the steady state conditions listed in Table 13 and then stepping down the current of one of the simulated vehicles in 10A increments until 50 A is reached; similar to the nominal

power transfer experiment conditions procedure of Section 2.2.1. This evaluation requires coordination of additional lab equipment to properly load both ports of the EVSE.

Table 13. Delta 350kW EVSE Multi-Port/Multi-Session Simultaneous Charging Test Conditions

Connector CCS A Voltage [VDC]	Connector CCS B Voltage [VDC]	Connector CCS A and CCS B Current [ADC]
400	400	500
850	400	500
850	850	500
400	400	150
850	400	150
850	850	150

The procedure and requirements for evaluation of multi-port simultaneous charging are as follows:

- Record the vehicle emulator make/model for both connections, EVSE make/model and firmware version, ambient temperature, day/time, OCPP server version, etc.
- Set voltage and current targets for both simulated vehicles in accordance with Table 13.
- Begin collecting data for at least 60 seconds before plugging in.
- Plug in EVSE connector A, begin charging sequence, and record plug-in time.
- Observe load current ramp for connector A to ensure power is flowing before plugging in EVSE connector B.
- Plug in EVSE connector B, begin charging sequence, and record plug-in time.
- Observe load current ramp for connector B to ensure power is flowing.
- Collect quasi-steady state power transfer data for at least 180 seconds.
- Reduce current for the EVSE charging on connector B by 10A and collect steady-state power transfer data for at least 180 seconds to allow the system to reach quasi-steady state conditions. Repeat this step until 180 seconds of power transfer data is collected at a load current of 50 A.
- Stop charging with EVSE side B and unplug.
- Stop charging with EVSE side A and unplug.
- Continue to collect data for a minimum of 60 seconds after unplugging.

2.2.6.2 Results

Multi-port/multi-session evaluations were conducted for every experiment condition listed in Table 13. No major issues were found in any of the experiments and the power output of CCS connector A held steady while CCS connector B was swept through the load steps. Additional lab equipment was required to load the second EVSE connection and record data making the setup slightly more complex.

Figure 20 depicts the AC and DC voltage and current waveforms recorded during the Delta 350kW EVSE 400VDC/400VDC 150ADC multi-port/multi-session experiment. Overall, the Delta 350kW EVSE handles simultaneous charging sessions without major issue. It is observed

that a small perturbation occurs in the output current CCS connector B when current steps from 90ADC to 80ADC, charging power recovers to the requested level in about 40 seconds. The cause of this disturbance cannot be known for sure, but it is believed that this transient is caused by a failure in one of the Delta 350kW EVSE's 14 25kW power modules. Over the course of Delta 350kW EVSE performance evaluations, there were four instances where a power module failed and the project team made every effort possible to run all 32 of the completed characterization experiments with the EVSE in a condition capable of outputting full nameplate power. This disturbance can also be observed in the AC input voltage and current profiles and a similar disturbance can be observed in the 400VDC/400VDC 500ADC multi-port/multi-session experiment depicted in Figure 21, but these cases the disturbance does not interrupt the charge session. One other unexplained disturbance in AC input voltage is observed during the CCS B 70ADC current step but does not otherwise affect the operation of the EVSE.

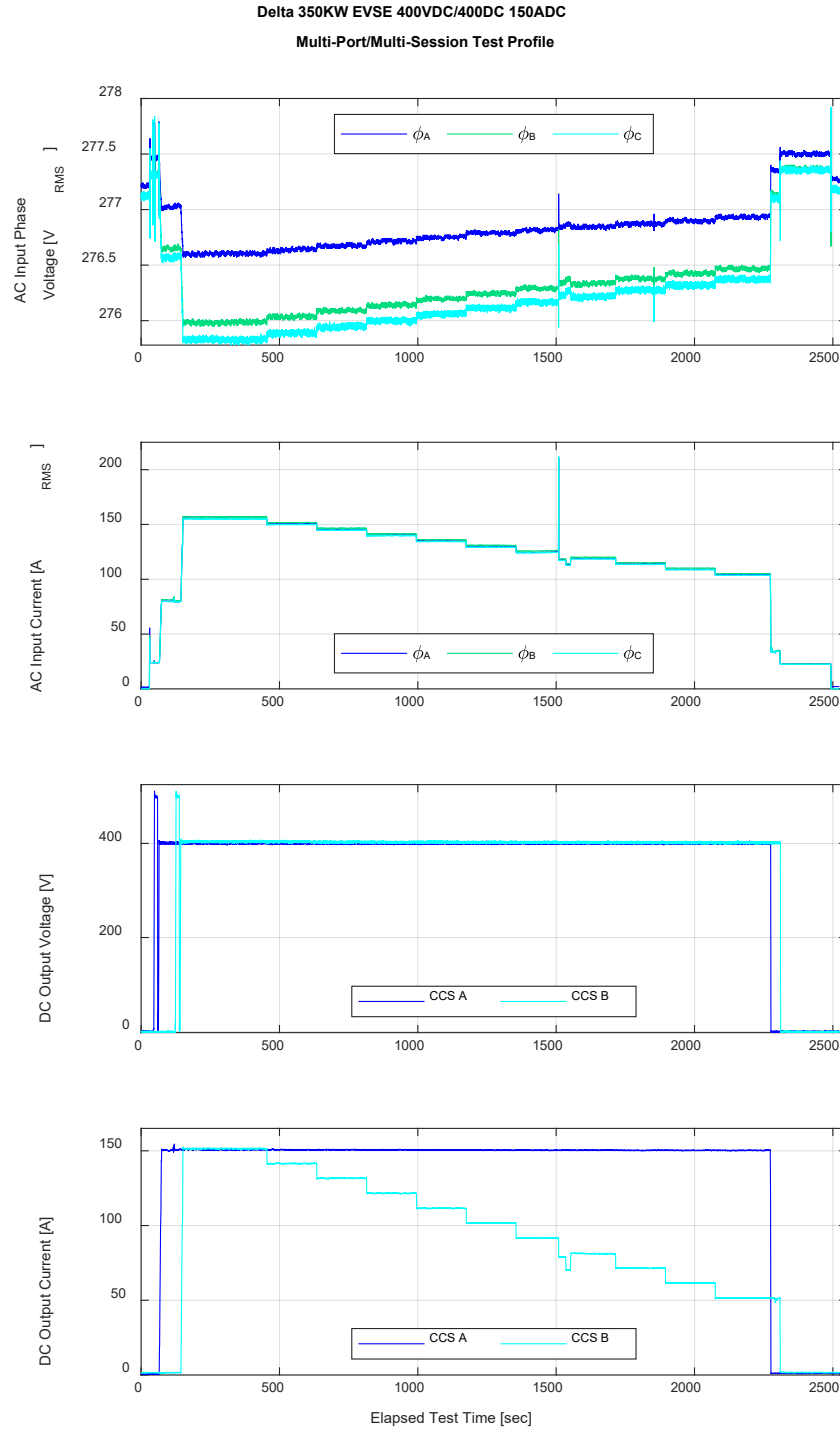


Figure 20. Delta 350kW EVSE 400VDC/400VDC 150ADC Multi-Port/Multi-Session Experiment Profile

Table 14 lists the average efficiency for each Table 13 experiment performed. Once both sides are connected and power is flowing to the vehicles, the efficiency curve is relatively flat with the minimum average efficiency during simultaneous charging being 94.37%.

Table 14. Multi-Port Average Efficiencies

Connector CCS A Voltage [VDC]	Connector CCS B Voltage [VDC]	Connector CCS A and CCS B Current [ADC]	Average Efficiency [%]
400	400	500	94.37
850	400	500	94.90
850	850	500	95.11
400	400	150	95.17
850	400	150	95.28
850	850	150	95.66

The Table 13 evaluation regimen revealed that when the second vehicle is plugged in to the Delta 350kW EVSE, the EVSE's 350kW charging capacity is divided in half between the two vehicles: vehicle #1 can charge up to 175kW, and vehicle #2 can charge up to 175kW. This limitation is enforced for the entirety of the time that the two vehicles are connected to the Delta 350kW EVSE: once one vehicle disconnects, the second vehicle can ramp up charging power to the amount of power requested. This limitation does not change depending on charging capabilities of the connected EV's: if vehicle #1 connects and charges at its maximum charging power of 200kW and vehicle #2 connects and charges at its maximum charging power of 100kW, the by the EV within the limitations of the EVSE's full power 350kW nameplate rating. Delta 350kW EVSE should be able to provide the requested power of both vehicles simultaneously, as the total requested 300kW of charging power is within the EVSE's limit of 350kW. However, in practice vehicle #1 will charge at a rate of 175kW while vehicle #2 is connected and charging at the requested maximum power of 100kW. A more effective EVSE charging strategy would modulate available charging power between connected vehicles, so that in the previous example, vehicle #1 can charge at its requested power of 200kW while vehicle #2 charges at its requested power of 100kW. Such a charging strategy would make more effective use of installed DC charging infrastructure, minimize dwell times, station queueing and costs as discussed in more detail in (Gaxiola, Gadamsetty and Davidson 2025). Consequently, additional study that investigates how charging limits are communicated to vehicles makes recommendations to optimize power delivery is warranted. Figure 21 depicts the behavior of this charging strategy during the 400VDC/400VDC 500ADC multi-port/multi-session experiment. Vehicle #1 plugs in and requests 200kW at 500ADC and 400VDC and receives that power briefly until vehicle #2 connects and also requests 200kW at 500ADC and 400VDC. From that point forward, both vehicles receive 175kW while vehicle #2 steps down requested charging power and eventually disconnects. At that point, vehicle #1 resumes charging at 200kW until the charge session is terminated.

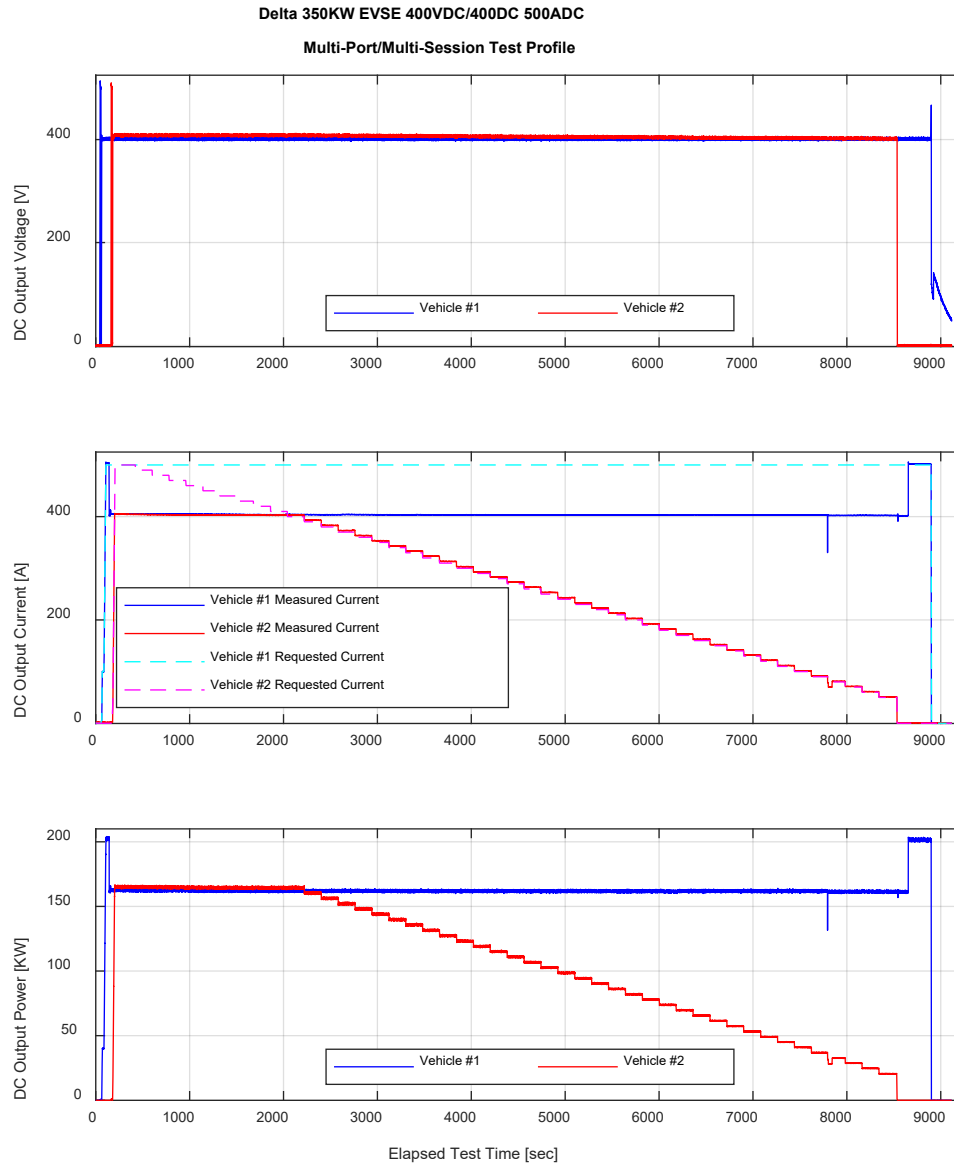


Figure 21. Delta 350kW EVSE 400VDC/400VDC 500ADC Multi-Port/Multi-Session Experiment Profile

3 Conductive Power Transfer EVSE Characterization Results and Analysis

This section compares the Delta 350kW EVSE performance with EVSE characterized in (Carlson and Onar 2023) and (Kogalur, et al. 2025) which are publicly available for detailed review.

3.1 Nominal Conditions Power Transfer Test Results

Figure 22 depicts the DC output current ripple for 400VDC nominal conditions evaluations performed on EVSE1, EVSE2 and the Delta 350kW EVSE. The current ripple of the Delta 350kW EVSE has slightly worse regulation but is on par with the performance of EVSE2. The DC output current regulation of EVSE1 is roughly five times worse than EVSE2 or Delta 350kW EVSE.

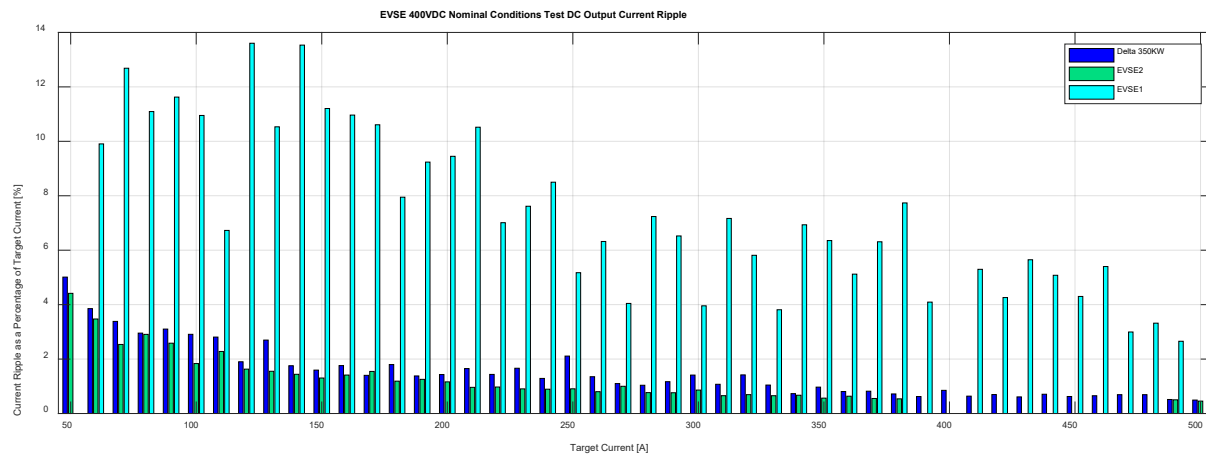


Figure 22. EVSE DC Output Current Ripple for 400VDC Nominal Conditions Experiment

Figure 23 depicts the AC grid input to DC vehicle output power conversion efficiency profile for 300VDC nominal conditions experiments performed on EVSE1, EVSE2 and Delta 350kW EVSE. The AC-to-DC conversion efficiency of the Delta 350kW EVSE is the highest of the three evaluated EVSEs but is on par with the performance of EVSE2. The AC-to-DC conversion efficiency of EVSE1 is the lowest of the three evaluated EVSEs and the profile is noisy due to the poor current regulation noted earlier in this section and in (Kogalur, et al. 2025).

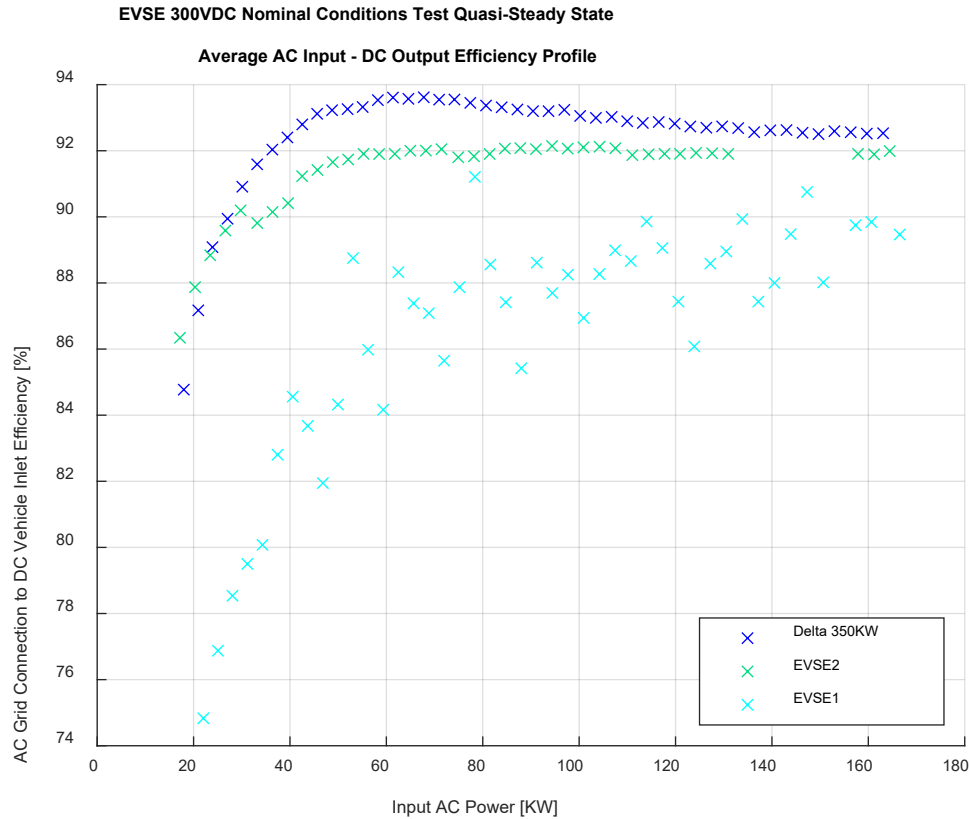


Figure 23. EVSE AC Input to DC Output Power Conversion Efficiency Profile for 300VDC Nominal Conditions Experiment

Figure 24 depicts the AC power factor profile for 300VDC nominal conditions experiments performed on EVSE1, EVSE2 and Delta 350kW EVSE. The power factor of all three evaluated EVSEs is roughly equivalent at high load levels, while the power factor of EVSE1 falls off more steeply with decreasing load than the power factor of the Delta 350kW EVSE or EVSE2. The excellent power quality of the Delta 350kW EVSE is attributed in part to its excellent power conversion efficiency. Comparison of current total harmonic distortion during nominal conditions power transfer evaluations cannot be directly compared due to differences in how current THD was recorded and quantified for the different EVSEs, thus making direct comparisons invalid.

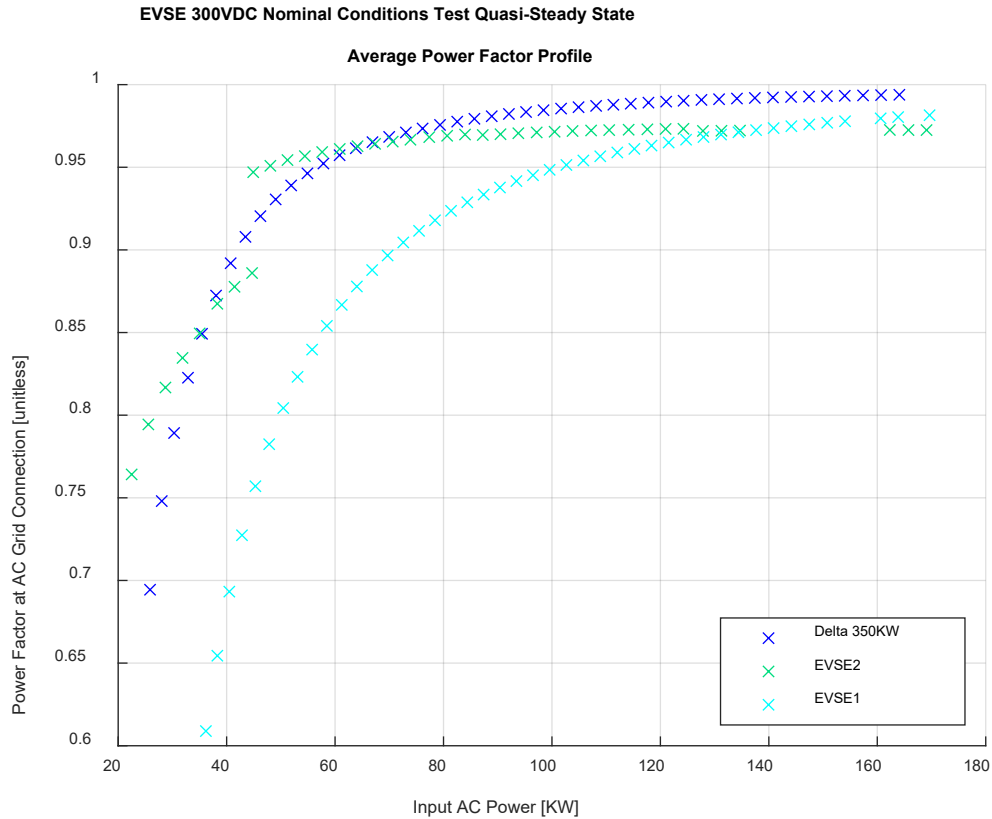


Figure 24. EVSE Power Factor Profile for 300VDC Nominal Conditions Experiment

Figure 25 depicts the AC-DC power conversion loss profile for 300VDC nominal conditions experiments performed on EVSE1, EVSE2 and Delta 350kW EVSE. In keeping with the trend of the other figures presented in this section, the AC-DC power conversion loss of the Delta 350kW EVSE is the most optimal of the three EVSE performance characterizations presented here: the Delta 350kW EVSE power conversion loss is roughly 1kW lower than the power conversion loss of EVSE2 across a majority of the EVSE operating window. The EVSE1 power conversion loss profile is noisier and roughly 5kW higher than the other two EVSEs across the range EVSE operation.

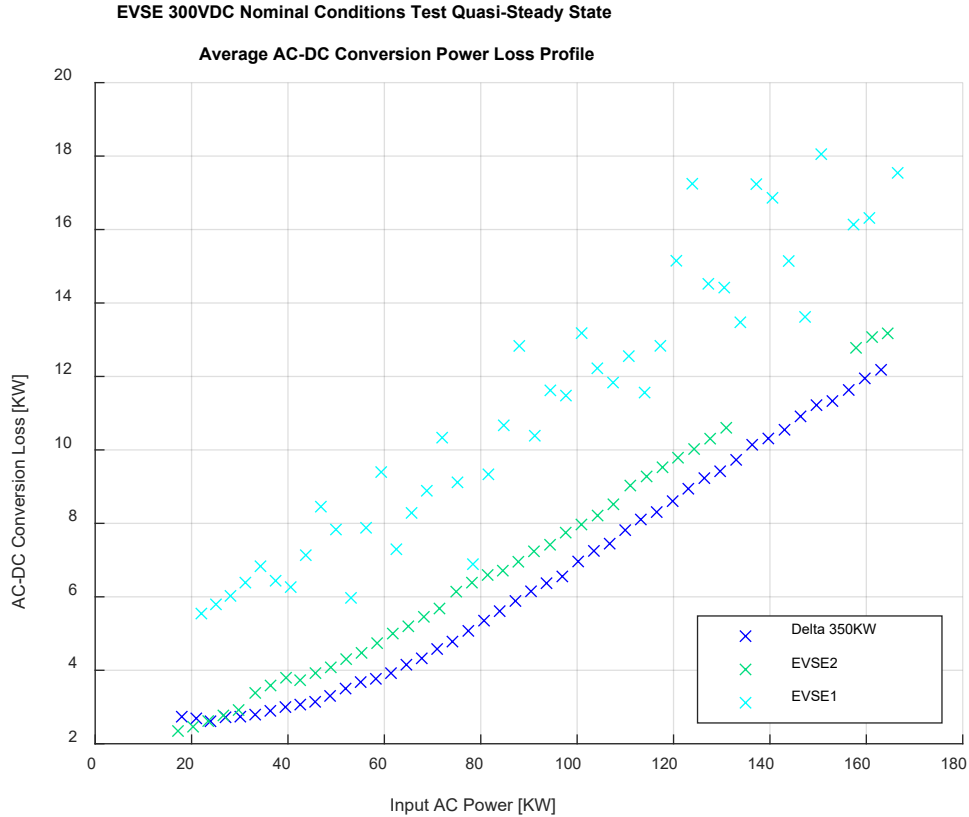


Figure 25. EVSE AC-DC Conversion Power Loss Profile for 300VDC Nominal Conditions Experiment

3.2 Off-Nominal Grid Input Conditions Test Results

Figure 26 depicts the DC output current for the 400VDC 500ADC off-nominal AC input voltage variation experiments performed on EVSE1 and the Delta 350kW EVSE. It is observed that the DC output current is independent of the AC input voltage transient despite EVSE1's inferior current regulation.

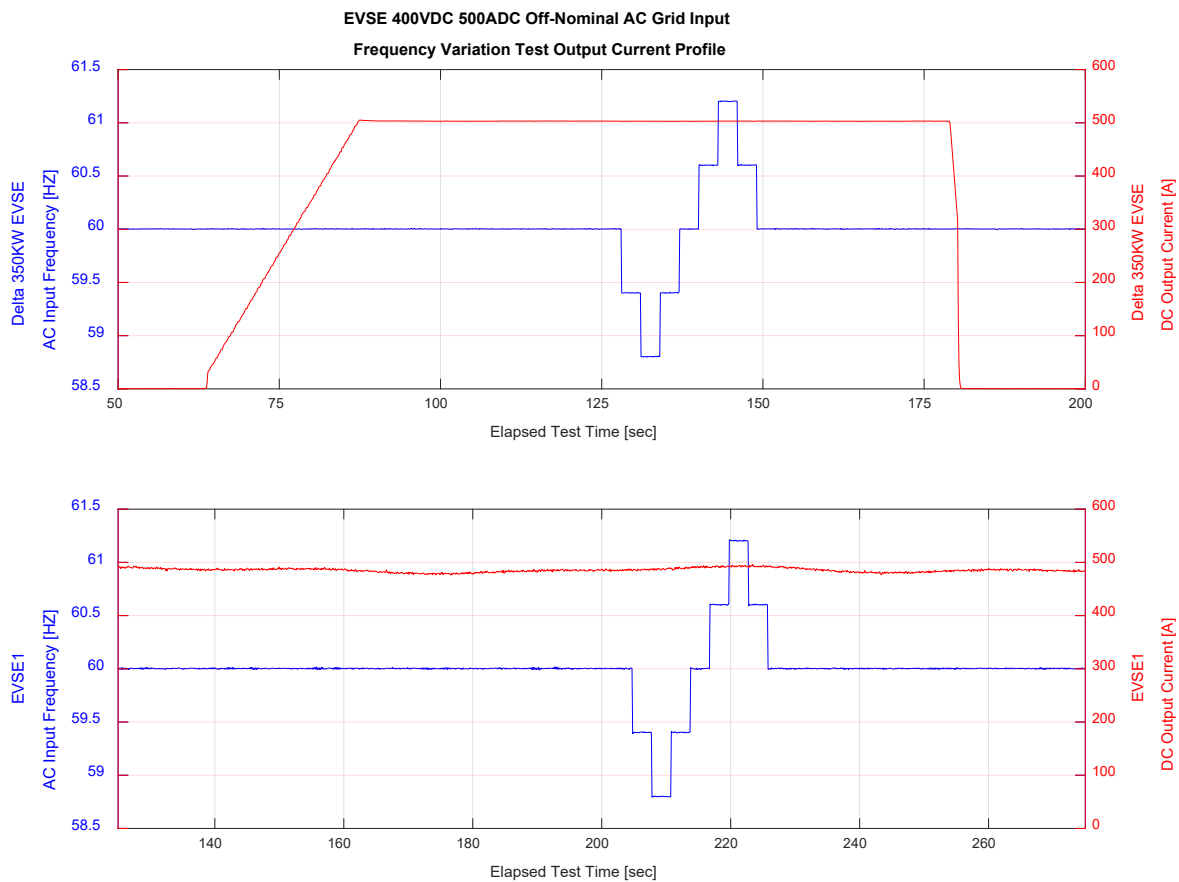


Figure 26. EVSE DC Output Current Profile for 400VDC 500ADC Off-Nominal AC Grid Input Voltage Variation Experiment

Figure 27 depicts EVSE power factor profile for the 400VDC 500ADC off-nominal AC input voltage variation experiments performed on EVSE1 and the Delta 350kW EVSE. Both EVSE's exhibit similar behavior where a decrease in AC grid input voltage results in an increase in AC power factor and an increase in AC grid voltage results in a decrease in AC grid power factor. The slope observed in the EVSE1 power factor profile is attributed to the fact that EVSE1 has two AC-DC conversion power cabinets that operate in parallel, so EVSE power factor was calculated by weighting the power factor of each cabinet by the total amount of power produced by each cabinet. Because the cabinets do not operate with equal loading, a change in load balance causes power-weighted EVSE power factor to exhibit the slope seen in Figure 27.

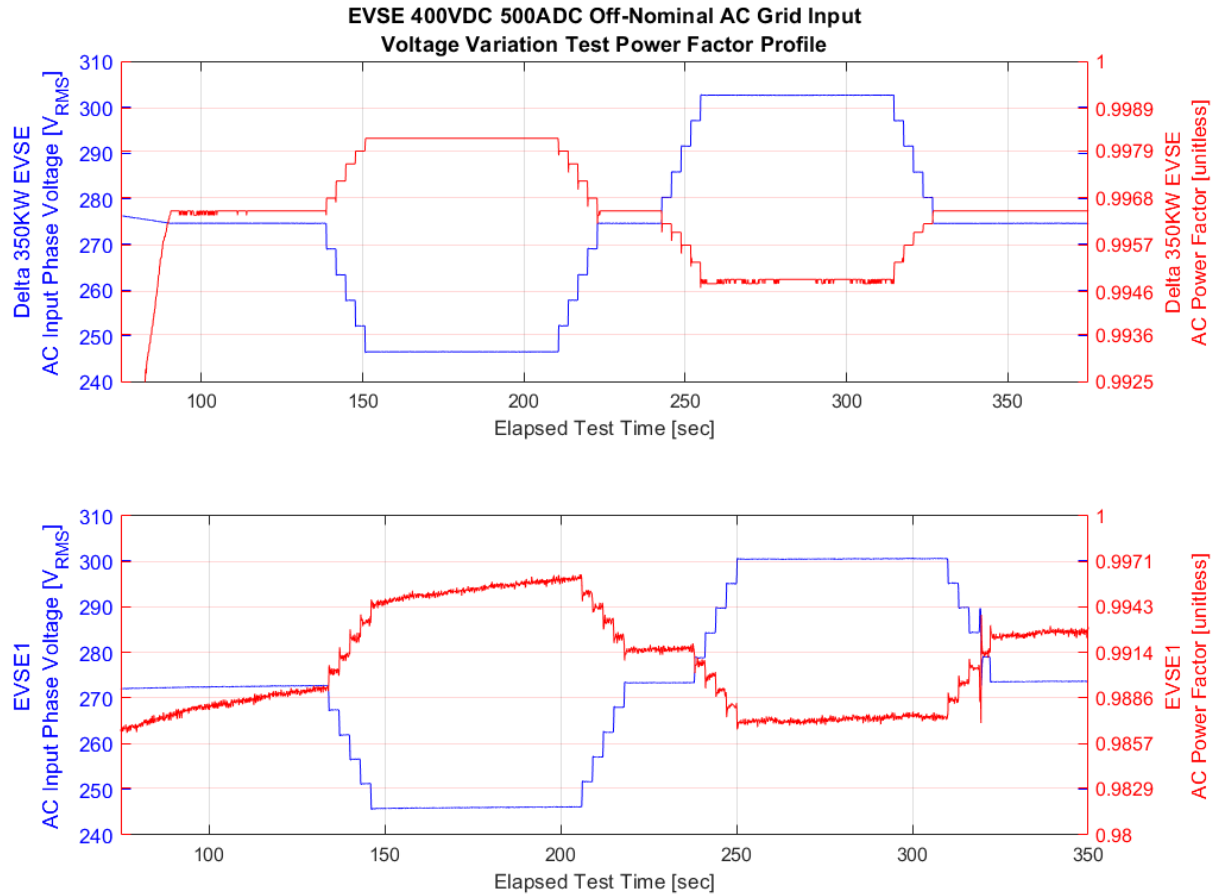


Figure 27. EVSE DC Power Factor Profile for 400VDC 500ADC Off-Nominal AC Grid Input Voltage Variation Experiment

Figure 28 depicts the DC output current for the 400VDC 500ADC off-nominal AC input frequency variation experiments performed on EVSE1 and the Delta 350kW EVSE. Both EVSE's exhibit similar behavior where a change in AC grid input frequency is independent of the AC input frequency transient despite EVSE1's inferior current regulation.

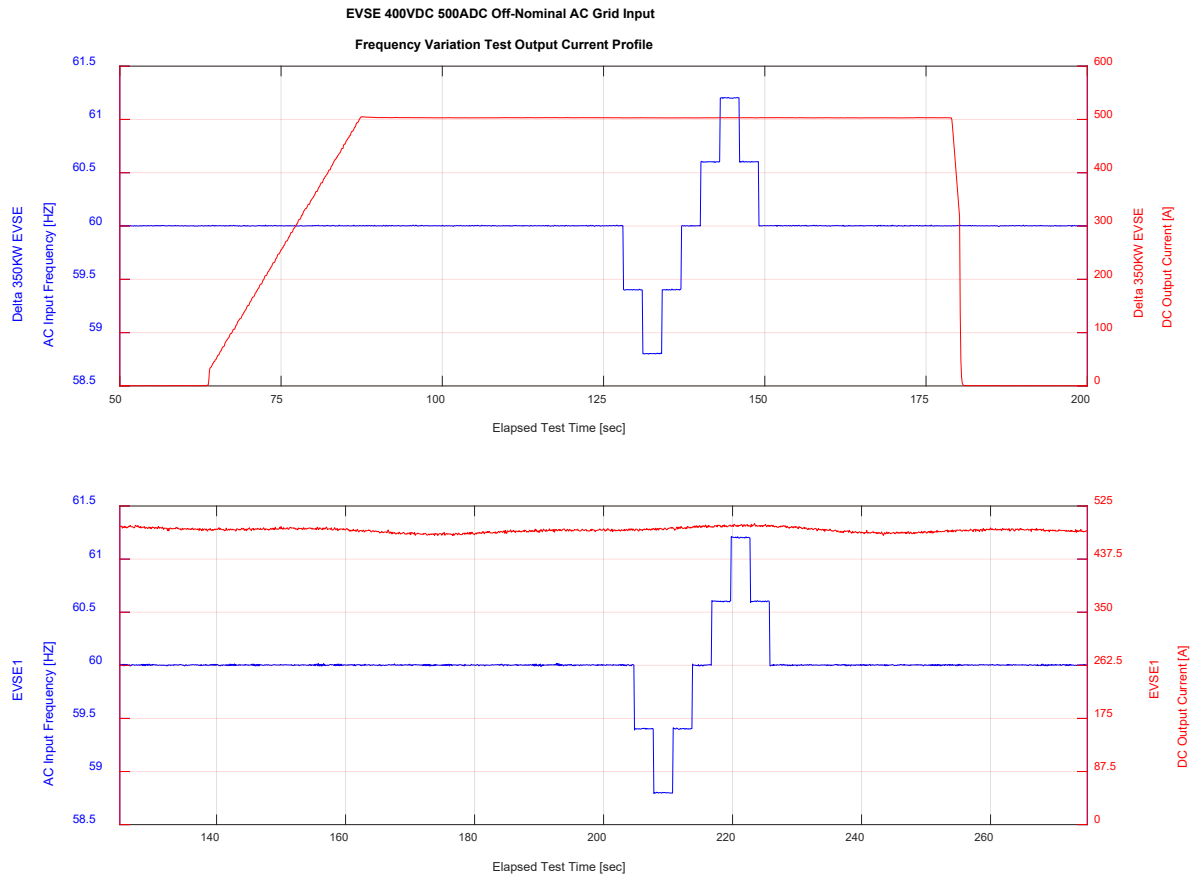


Figure 28. EVSE DC Output Current Profile for 400VDC 500ADC Off-Nominal AC Grid Input Frequency Variation Experiment

Comparison of current total harmonic distortion during off-nominal conditions harmonics injection testing cannot be directly compared; the individual test results are valid, but differences in how current THD was recorded and quantified for different EVSEs make direct comparisons invalid. See (Kogalur, et al. 2025) and (Carlson and Onar 2023) for details of off-nominal conditions harmonics injection evaluations performed on EVSE1 and EVSE2. Other EVSE2 off-nominal grid input conditions experiments cannot be directly compared to EVSE1 and Delta350kW EVSE due to differences in experiment configuration and conduct, thus making direct comparisons invalid. See (Carlson and Onar 2023) for details of EVSE2 grid input conditions evaluations.

3.3 Off-Nominal Ambient Temperature Conditions Test Results

Off-nominal ambient temperature experiments of the Delta 350kW EVSE were not performed due to limitations of supporting laboratory equipment. See (Kogalur, et al. 2025) and (Carlson and Onar 2023) for details of off-nominal conditions ambient temperature evaluations performed on EVSE1 and EVSE2.

3.4 Off-Nominal Smart Charge Management Conditions Test Results

Table 15 lists a comparison of EVSE OCPP power curtailment performance metrics for the Delta 350kW EVSE and EVSE1. *TxProfile* command responses are not included as the Delta 350kW EVSE does not implement the *TxProfile* command from the OCPP standard and was not responsive to *TxProfile* commands sent. It is observed that EVSE1's response to OCPP commands is roughly 500 to 1000 milliseconds faster than the Delta 350kW EVSE for all evaluations. EVSE1 DC current ramp up and ramp down rates are faster than Delta 350kW EVSE ramp rates for all evaluations.

Table 15. EVSE OCPP Power Curtailment Performance Metrics for Smart Charge Management Conditions Tests

EVSE	Curtailment Command	DC Load Voltage [V]	DC Load Current [A]	Latency from Command to Power Ramp [sec]	Ramp-Down Rate [A/sec]	Ramp-Up Rate [A/sec]
Delta 350kW	MaxChargePoint	400	150	1.451	-224.6	21.7
EVSE1	MaxChargePoint	400	150	0.927	-387.2	415.0
Delta 350kW	MaxChargePoint	400	500	1.566	-1138.4	659.5
EVSE1	MaxChargePoint	400	500	0.838	-2098.2	2038.8
Delta 350kW	TxDefaultProfile	400	150	1.507	-229.5	20.4
EVSE1	TxDefaultProfile	400	150	0.693	-402.0	435.4
Delta 350kW	TxDefaultProfile	400	500	1.462	-1517.6	643.4
EVSE1	TxDefaultProfile	400	500	0.871	-2075.9	2110.6

EVSE2 off-nominal smart charge management conditions experiments cannot be directly compared to EVSE1 and Delta350kW EVSE due to differences in network configuration when the evaluation was conducted, thus making direct comparisons invalid. See (Carlson and Onar 2023) for details of EVSE2 off-nominal smart charge management conditions evaluations.

3.5 Off-Nominal Thermal Control System Conditions Test Results

Figure 29 compares the results of the off-nominal thermal control system evaluations performed on EVSE2 and Delta 350kW EVSE. The off-nominal thermal control system experiment was not performed on EVSE1 due to supporting laboratory equipment limitations. After approximately six minutes of charging at full power, EVSE2 imposes a thermal curtailment of DC charging current of approximately 90ADC. As noted in (Carlson and Onar 2023), the only known method to remove the current limit was to cycle power to the EVSE. The current curtailment contributes to the differences in temperature profile of panels three through five. It is also noted that the time interval between charge sessions for the Delta 350kW EVSE is slightly longer than that for EVSE2; this could be attributed to a longer handshake between EV and EVSE after EV connector is plugged in, or it could be related to a shorter EVSE2 rest interval as the Delta 350kW EVSE rest interval was exactly five minutes. Because the Delta 350kW EVSE does impose a thermal charging power curtailment during any of the three sequential high current and

high power charging events, it is observed that the performance of the Delta 350kW EVSE thermal control system is superior to that of EVSE2.

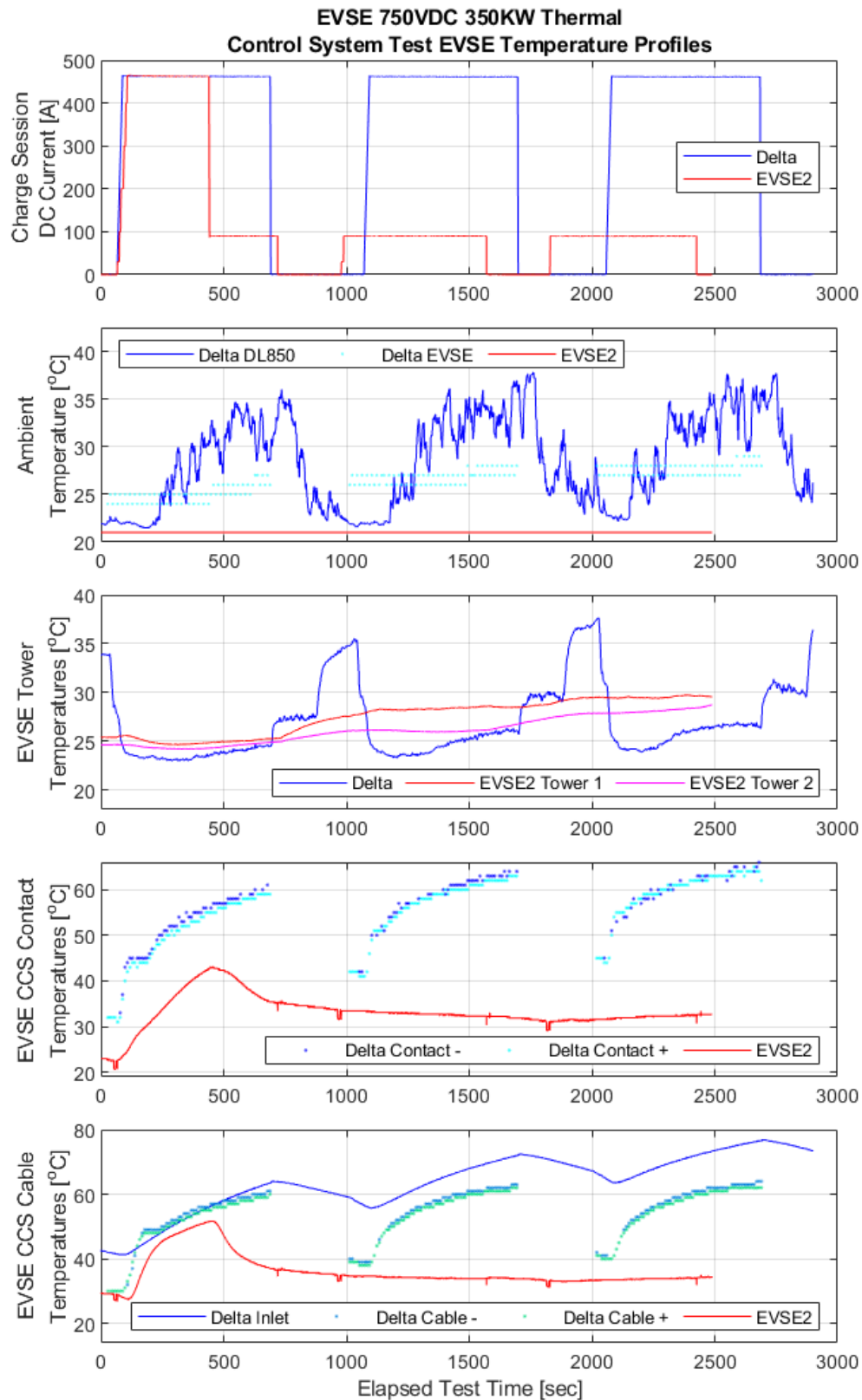


Figure 29. EVSE Thermal Control Systems Experiment Instrumented Temperature Profile

3.6 Off-Nominal Multi-Port Simultaneous Charging Conditions Test Results

Delta 350kW EVSE is the only EV charging system characterized in the NextGen Profiles project that is capable of multi-port/multi-session simultaneous charging. No comparison to EVSE1 or EVSE2 is presented here as EVSE1 and EVSE2 are only capable of charging one EV at a time.

4 Conclusion

EVSEs were operated under varied real-world conditions comprising a set of nominal and off-nominal evaluations. This report complements the *A NextGen Profiles Project Report* and *EVs@Scale: NextGen Profiles: EVSE Characterization 2024* with additional experiment data, outcomes and evaluation related to EVSE performance by summarizing all activities conducted to date and presents new data and results collected between October 2024 and December 2025 on the Delta Electronics 350kW Electric Vehicle Charging System.

Under nominal conditions, the Delta 350kW EVSE demonstrated excellent precision and accuracy in regulating DC output current with minimal steady-state error. On many metrics the performance of the Delta 350kW EVSE met or exceeded that of EVSE1 and EVSE2. Efficiency of all EVSEs followed a consistent trend, remaining lower at light loads and improving significantly once the delivered power exceeded approximately 15% of the rated capacity while power factor also improves with load; $\approx 95\%$ at high voltage and power levels. Off-nominal temperature performance of the Delta 350kW EVSE and quantification of the amount of localized heating and effect of placement of EVSE cabinets on EVSE performance are areas of inquiry worthy of further study.

Off-nominal characterization evaluations revealed that the Delta 350kW EVSE maintained uninterrupted operation under all evaluated off-nominal conditions, indicating robust grid operation. Delta 350kW EVSE off-nominal Smart Charge Management response experiments performance was on par with other evaluated EVSEs; the OCPP 1.6J smart charging commands showed successful execution with power reduction and restoration occurring promptly, though *TxProfile* commands are not in the Delta 350kW EVSE's implementation of the OCPP protocol. The Delta 350kW EVSE is also the only EVSE characterized in the NextGen Profiles project to date that implements multi-port/multi-session simultaneous EV charging; simultaneous EV charging performance was satisfactory and improvements were identified to better utilize available EV charging capacity for shorter dwell times and queueing.

Overall, these comprehensive findings from high-power charging systems highlight important performance attributes of the next-generation EV charging technologies. The results underscore the critical role of evaluating HPC EVSEs under several boundary conditions in understanding system behavior in real-world applications. Evaluation of the Delta 350kW EVSE revealed outstanding AC to DC power conversion performance and robust response to off-nominal grid and operating conditions. Four failures of individual EVSE power modules during the course of NextGen Profiles performance characterization present cause for concern and opportunity for additional reliability evaluation and study. As EV charging moves toward higher power levels and broader deployment, optimizing system-level design for reliability, thermal performance, and grid responsiveness will be essential. Future research could include continued evaluations of the Delta hardware under off-nominal temperature conditions including multi-port/multi-session simultaneous charge experiments, in addition to collecting data on other high-power conductive chargers to augment the data collected for the U.S. DOE EVs@Scale consortium NextGen Profiles project.

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Appendices

A.1 Appendix A

Conductive EVSE Characterization Measurement Parameters

Measurement Location	Parameter	Phase	Units
Metadata	EVSE Unique ID	-	-
	EVSE Firmware/ Software version	-	-
	Vehicle emulator model #1 / information	-	-
	Vehicle emulator model #2 / information		
	Vehicle emulator ID	-	-
	Timestamp	-	MM/DD/YY hh/mm/ss.dd
480 VAC Line Input Voltage to each Power Cabinet	Voltage	A, B, C	V (RMS)
	Current	A, B, C	A (RMS)
	Frequency	A	Hertz
	Real Power	A, B, C	kW (RMS)
	Reactive Power	A, B, C	kVAR (RMS)
	Apparent Power	A, B, C	kVA (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	-	Curtailed request (A or kW)
EVSE Auxiliary System(s)	Voltage	DC	V
	Current	DC	A
	Power	DC	kW
EVSE Charge Pedestal Output	Connector #1 Voltage	DC	V
	Connector #1 Current	DC	A
	Connector #1 Power	DC	kW
	Connector #1 DC current ripple	DC	%
	Connector #1 Dispenser supply fluid temperature	-	°C

Measurement Location	Parameter	Phase	Units
	Connector #1 Dispenser return fluid temperature	-	°C
	Connector #2 Voltage	DC	V
	Connector #2 Current	DC	A
	Connector #2 Power	DC	kW
	Connector #2 DC current ripple	DC	%
	Connector #2 Dispenser supply fluid temperature	-	°C
	Connector #2 Dispenser return fluid temperature	-	°C
Vehicle Inlet Port	Voltage	DC	V
	Current	DC	A
	Power	DC	kW
	DC current ripple	DC	%
EVSE Auxiliary System(s)	Voltage	DC	V
	Current	DC	A
	Power	DC	kW
EVSE CCS Cable	CCS cable #1 temperature	-	°C
	CCS cable #2 temperature	-	°C
EVSE CCS Connector	CCS connector #1 temperature	-	°C
	CCS connector #2 temperature	-	°C
EVSE Power Cabinet	Power cabinet internal air temperature	-	°C