Performance Test Results: CTA-2045 Electric Vehicle Supply Equipment

Testing Conducted at the National Renewable Energy Laboratory

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Technical Update, October 2017

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THE ELECTRIC POWER RESEARCH INSTITUTE (EPRI) PREPARED THIS REPORT.

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ABSTRACT

Utilities and manufacturers are assessing CTA-2045 (previously CEA-2045) to determine the degree to which it meets the needs of consumers, aggregators, and utilities. The Electric Power Research Institute (EPRI) is facilitating a collaborative project to study the extent to which CTA-2045 provides compatibility and interoperability with the wide range of systems into which consumer loads might be connected. If a modular interface works as intended, achieving interoperability and being self-installable by consumers, it could significantly advance the state of demand response worldwide. One of these systems consists of electric vehicle service equipment (EVSE); this report details the laboratory evaluations of the system's capabilities.

Keywords
CEA-2045
CTA-2045
Demand response
DR ready
EVSE
Smart grid

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1
INTRODUCTION

In 2013 the Consumer Electronics Association[1] (now called the Consumer Technology Association) released the ANSI/CEA-2045 standard. This standard defines a modular communication interface intended to be designed into end-use loads to enable demand response (DR). The CEA-2045 standard has been described in detail in EPRI report 3002004020, *Introduction to the CEA-2045 Standard*[2].

Utilities and manufacturers are assessing this new standard to determine the degree to which it meets the needs of consumers, aggregators, and utilities. Electric Power Research Institute (EPRI) is facilitating a collaborative project that is specifically studying the extent to which CEA-2045 provides compatibility and interoperability with the wide range of systems into which consumer loads might be connected. If a modular interface works as intended, achieving interoperability and being self-installable by consumers, it could significantly advance the state of demand response worldwide. A detailed description of the CEA-2045 Field Demonstration project, including its goals and plan, has been provided in EPRI report 3002004009, *ANSI/CEA-2045 Field Demonstration Project Description*[3].

In addition to the field demonstration described above, the EPRI and a team of partners were selected by the National Renewable Energy Laboratory (NREL) to carry out a project to develop and test how smart, connected consumer devices can act to enable the use of more clean energy technologies on the electric power grid. This project was a component of the NREL Integrated Network Test-bed for Energy Grid Research and Technology (INTEGRATE) initiative and was awarded under RFP Number RCS-4-42326, Topic 1, “Connected Devices”.

The project team includes the following end-use technologies and companies, each of which are market leaders in their fields. All of which were installed and tested at NREL’s Energy Systems Integration Facility (ESIF) in Golden Colorado.

- Electric Vehicle Service Equipment (Siemens)
- Thermostat (Emerson)
- Solar Inverter (Fronious)
- Pool Pump (Pentair)
- Water Heaters (AO Smith)

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[1] Now known as the Consumer Technology Association.

[2] http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000003002004020

[3] http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000003002004009

Device-type Specific Requirements for CTA-2045 Devices

The end-use devices (loads) tested in this project were all designed using device-type specific requirements. These requirements and links to each document are listed in Table 1-1. The requirements were created through a collaborative effort by which utilities and technology providers participated. The intent of these requirements is to provide guidance by which manufacturers of end-use devices, communication hardware, and other service providers could use to help create a predictable, interoperable, data rich architecture.

Table 1-1
Device-type Specific Requirements

Document Name	EPRI Product ID
Demand Response-Ready Domestic Water Heater Specification, Preliminary Requirements for CEA-2045 Field Demonstration	3002002710
Demand Response-Ready Thermostat Specification, Preliminary Requirements for CEA-2045 Field Demonstration	3002002711
Demand Response-Ready Electric Vehicle Service Equipment Specification, Preliminary Requirements for CEA-2045 Field Demonstration	3002002712
Demand Response-Ready Heat Pump Water Heater Specification, Preliminary Requirements for CEA-2045 Field Demonstration	3002002719
Demand Response-Ready Variable-Speed Pool Pump Specification: Preliminary Requirements for CEA-2045 Field Demonstration	3002008320

The tests conducted at NREL were done so to measure the performance characteristics of each end-use device so that their potential to support the integration of renewables can be evaluated. This report includes include the results from the EVSE testing.

2
ELECTRIC VEHICLE SUPPLY EQUIPMENT

This section presents the test results from the Siemens electric vehicle charger, referred-to as Electric Vehicle Service Equipment (EVSE). The specific product tested was a VersiCharge model SG-2 with modified firmware to implement the advanced demand response features of this project. This product is a Level 2, 30[Amp] charger. The product had no physical modifications and is commercially available.

Testing was performed at EPRI and at NREL during a series of onsite visits by team members.

The test plan that guided this testing has been documented separately.

Test Setup

Figure 2-1 shows the test setup used for the EVSE testing at NREL. All testing was conducted using a normal grid connection feeding the AC circuit. The circuit feeding the EVSE was capable of the full 30[Amps] of the product. The NREL laboratory BEDAC (Building Energy Data Acquisition) system included a power quality meter that logged real and reactive power at a 1 second interval to support this test.

In addition, EPRI monitored the following directly from the EVSE using the CEA-2045 Simulator software:

- Present power consumption
- Cumulative energy consumption
- Present operating state
- Consumer override

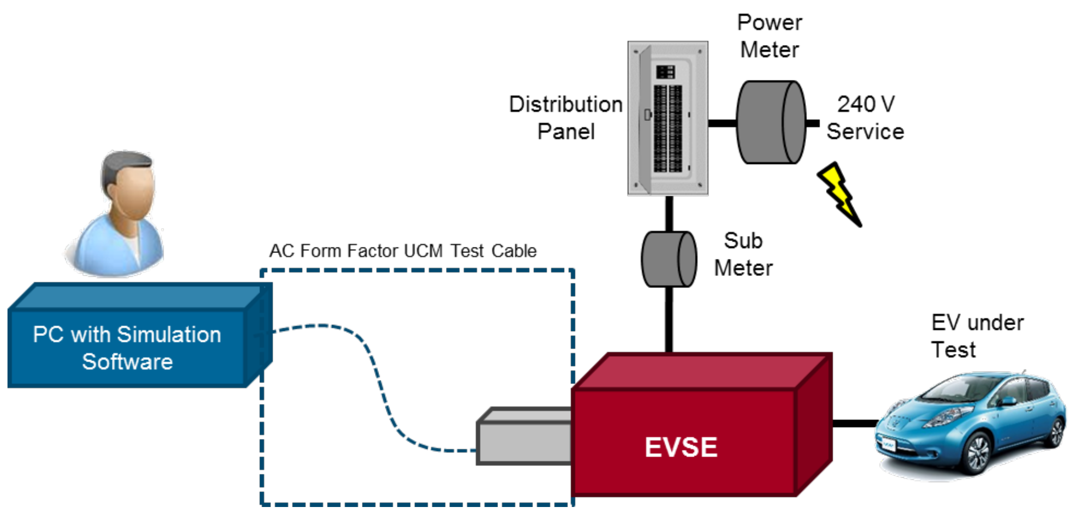

Figure 2-1
EVSC Test Setup

Figure 2-2 shows the installed EVSE in the laboratory at NREL. The CEA-2045 communication interface is accessed by opening the front cover of the charger as shown in the right frame. As indicated in the system diagram of Figure 2-1, the EPRI communication simulator (a PC-based tool) was plugged into the communication port during this testing. This simulator is a wired connection as seen in Figure 2-2 as a ribbon cable feeding in at the top of the EVSE.

Figure 2-2
EVSE Installed at NREL

Figure 2-3 shows the vehicle used for the test, a Scion iQev. The connection from the Siemens EVSE to the vehicle was via the standard SAE J1772 AC charging connection. This connection includes a pilot wire with a simple mechanism to enable (only) the following information to be exchanged:

- The EVSE can detect that a vehicle is connected via a particular DC voltage level on the pilot wire.
- The EVSE can detect via a different DC voltage level that a connected vehicle wants to receive charge (i.e. the 240Vac contactor to be closed).
- The EV can detect via the duty cycle of a PWM signal the maximum allowed charging current.

Figure 2-3
Electric Vehicle used for Testing

Device Identification

As indicated in Figure 2-1, the EPRI CEA-2045 Simulator software was used to communicate with the EVSE, monitoring its status and managing its behavior throughout the test. This software is designed to plug-in directly to the CEA-2045 port interface at which communication modules would normally be connected.

The unit's identification was queried and reported as indicated in Figure 2-4. This includes a device-type code indicating "EV Supply Equipment – Level 2", as well as a unique vendor ID, serial and model numbers.

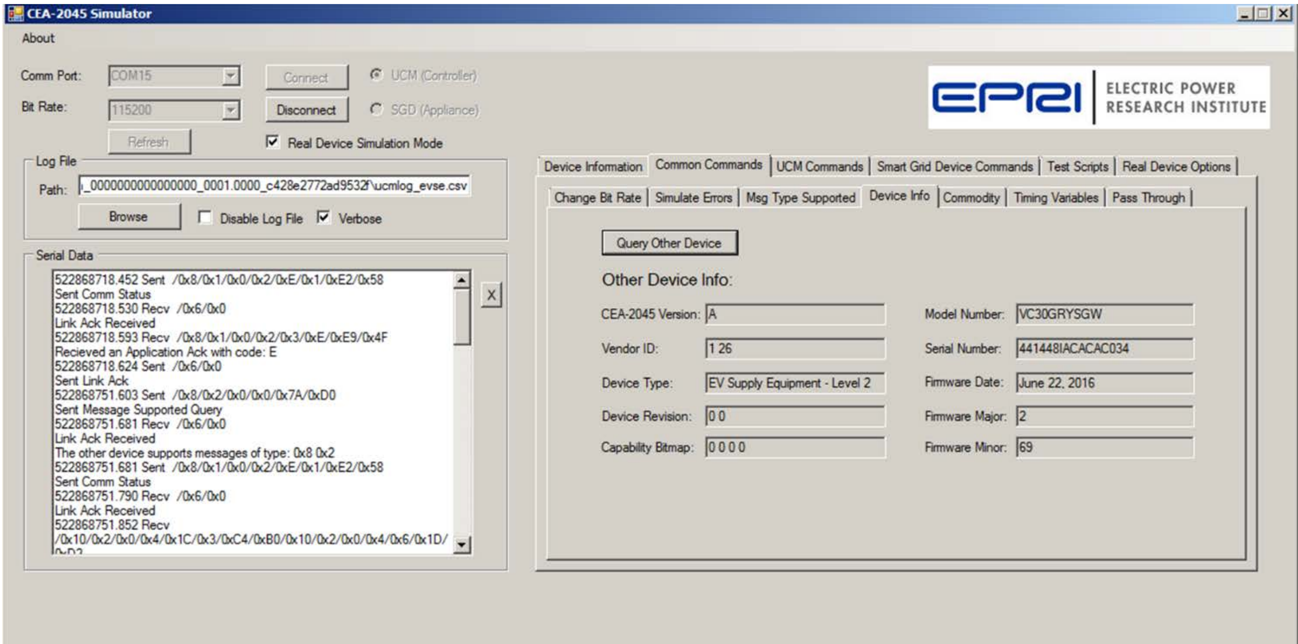

Figure 2-4
Communication Interface Showing Device Identification

Baseline Behavior

The CEA-2045 standard identifies three monitorable parameters that are of particular relevance to EVSEs and were supported in the Siemens units involved in this test:

- Present power consumption. The standard does not dictate how a manufacturer must make this calculation (measured or estimated). For the Siemens EVSE, it was metered.
- Cumulative energy consumption (based on the power values over time).
- Operating status – a parameter that includes whether or not the system is actively charging and whether or not a control event is in effect.

The baseline behavior of the EVSE is shown in Figure 2-5. Testing was started with the vehicle in a discharged state. Discharging the vehicle was outside the scope of this test and occurred by driving the vehicle. Because standards do not exist to allow the EVSE to discover the vehicle's state of charge, this was monitored manually at points throughout the testing from the vehicle dashboard.

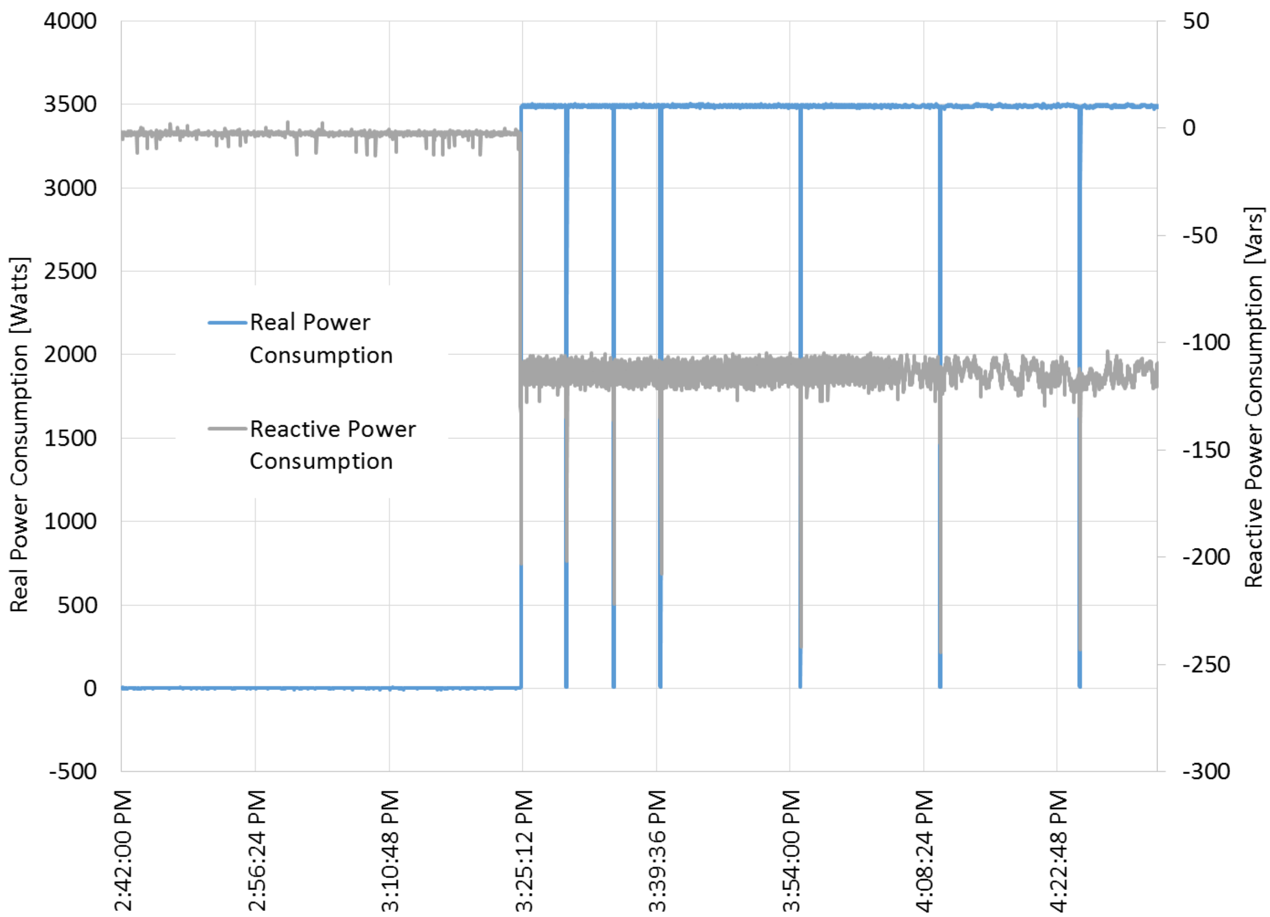

Figure 2-5
EVSE Baseline Behavior

As indicated in the figure, the vehicle was plugged-in and charging commenced at approximately 3:25 PM. The test vehicle's maximum rate of charging was 3500[Watts]. The reactive power level was also monitored and was around -110[Vars] as shown. This is a power factor of better than 0.999.

During idle operation prior to the vehicle being plugged-in, the EVSE was queried for its operating state and reported "Idle Normal". After the vehicle was connected and charging commenced, it was again queried and reported "Running Normal".

After charging commenced, the vehicle can be seen to pause charging briefly at certain intervals, notionally to assess the battery state. Each time a charging session was initiated, the vehicle would do this three times at a ~5 minute interval then ~every 15 minutes thereafter, as evident in Figure 2-5. This continued throughout the charging cycle and can be seen in all the test results herein.

Figure 2-6 provides a closer view of one of these charging pauses, with 1-second power measurement points shown. This also shows that the ramp-up of charging was controlled by the EV, rising from 0 to 3500[W] took place over ~2[seconds].

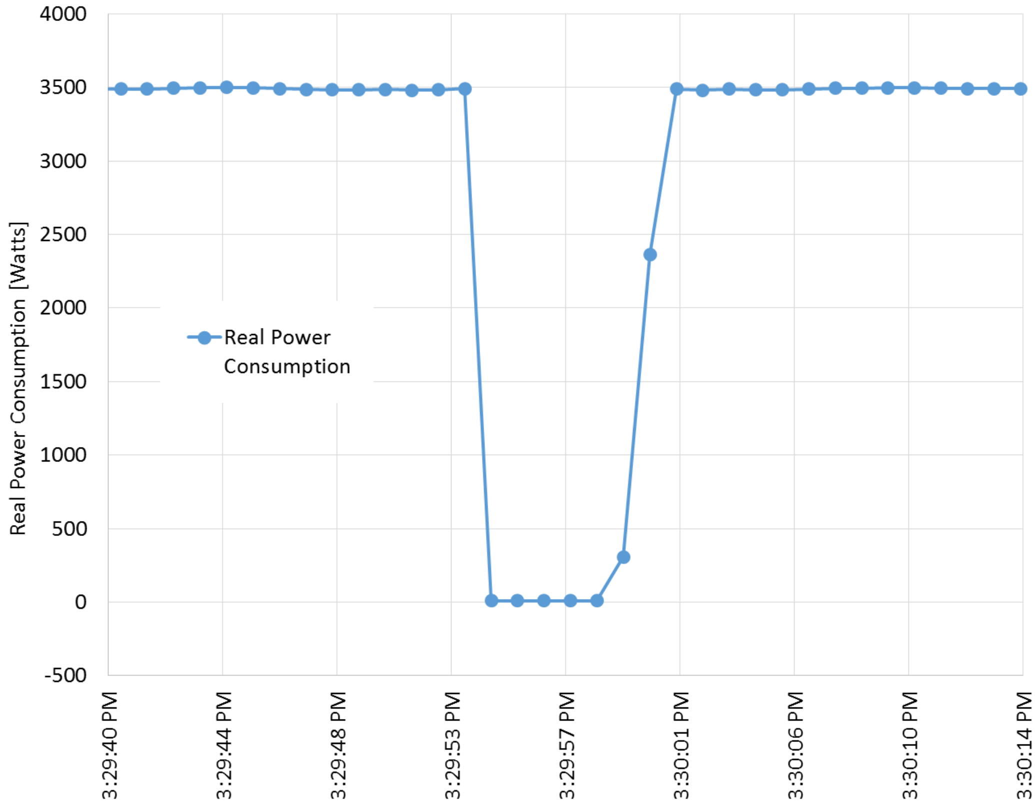

Figure 2-6
Electric Vehicle Pause in Charging

The Siemens EVSE includes a manual adjustment to limit the maximum charge level to levels below 30[Amps]. Because the EV used in this testing had a maximum charging rate of 3500[Watts] (~14.6[Amps] at 240[Vac]), the EVSE was adjusted to 75% or 22.5[Amps] maximum. This resulted in the expected behavior shown in Figure 2-7 for this test.

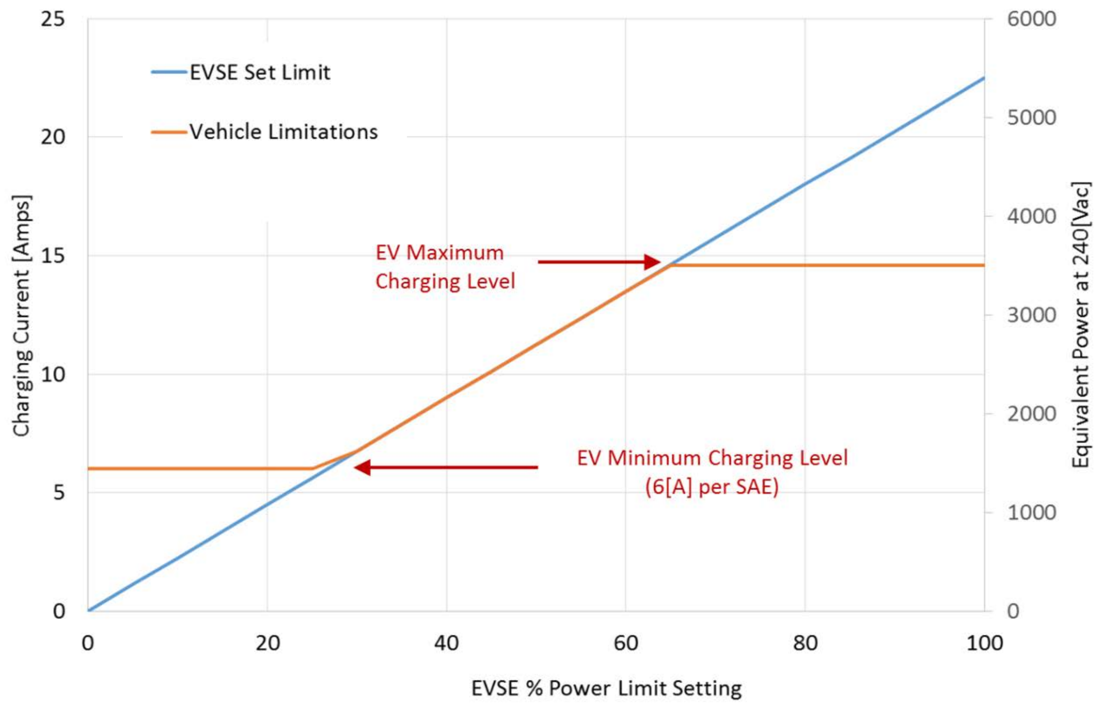

Figure 2-7
Expected Behavior based on EV and EVSE Characteristics as Tested

Visual Indicators

The EVSE included LED visual indicators and Controls as shown in Figure 2-8.

Communication Status Indicator: This indicator is illuminated based on the communication status messages delivered to the EVSE from the communication system. If lit, this indicates that communication through to the head-end system is good.

Charging Status Indicator: This indicator is illuminated when the EVSE is charging a vehicle and blinks when a control or event is in effect that alters the EVSE's normal mode of operation in any way.

Consumer Event Override Button: This allows consumers to opt-out of control events that may be in effect or may occur in the next 12 hours.

Figure 2-8
Visual Indicators and Controls on EVSE

Shed Event

The results from the testing of the EVSE's basic "Shed" function are summarized in Figure 2-9. This test was conducted on July 27th, 2016. The Shed event was sent with a 15-minute duration and the EVSE was allowed to return to normal operation autonomously based on this duration.

As noted in the baseline test results, the EV momentarily pauses charging occasionally. These spikes can be ignored for the purposes of the Shed and other test results.

To the left side of the figure, prior to calling the Shed event, the EVSE can be seen running in a normal mode of operation for reference, with the vehicle charging at 3500[W].

At 1:48PM, a basic "Shed" event was initiated. The EVSE executes this by limiting the charge current to 50% of the maximum, or 50% of 22.5[A] = 11.25[A] = ~2700[W]. The device under test reduced to a measured value of 2640[W]. At 2:03PM, 15 minutes after the event began, the charging level returned to 3500[W].

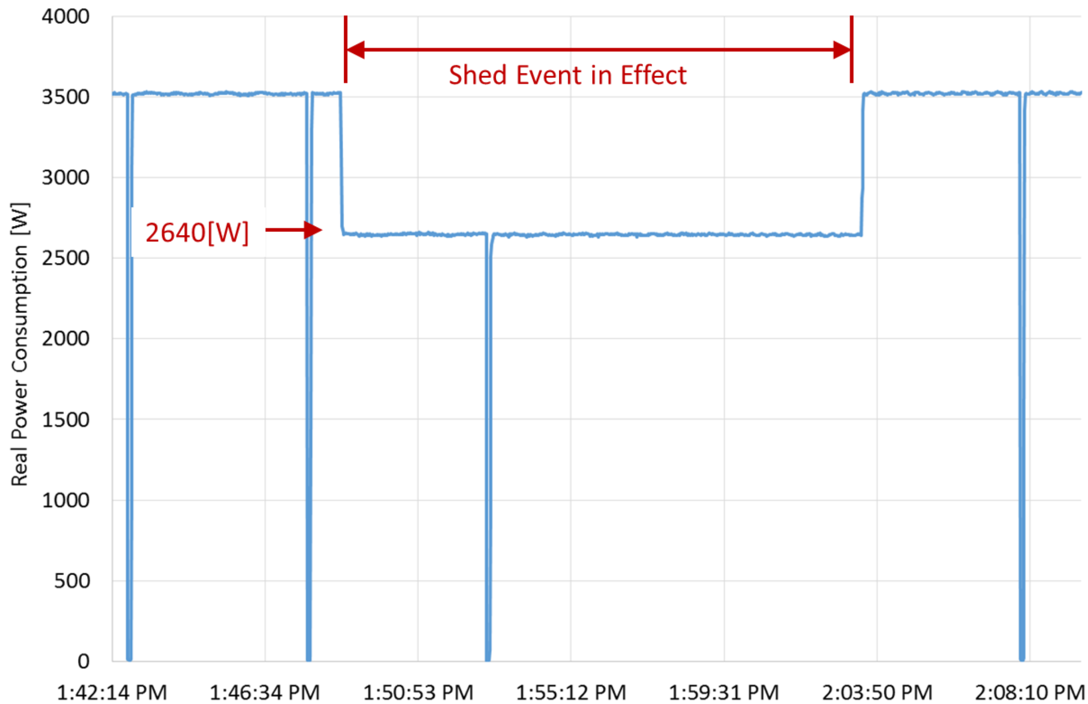

Figure 2-9
Shed Event

During normal operation prior to the Shed event, the EVSE was queried for its operating state and reported "Running Normal". During the Shed event, it was again queried and reported "Running Curtailed Grid".

Determining how much to curtail during an event is a matter of ongoing discussion. Stakeholders agree that ensuring consumer satisfaction is the highest priority in order to increase participation in advanced grid programs, and that the vehicle must be ready for the consumer when needed. Ideally, the EVSE would be able to query the vehicle for its state of charge and limit the depth and duration of grid responses so as to guarantee that the vehicle is fully-charged when needed.

The curtailment level of 50% utilized in this test is an initial choice of the project team, not specified in any standard, and could be changed to something more or less aggressive as more field experience with EVSEs is gained.

Critical Peak Event

The results from the test of the EVSE's "Critical Peak" function are summarized in Figure 2-10. This test was conducted on July 27th, 2016. The Critical Peak event was sent with a 15-minute duration, and the EVSE was allowed to return to normal operation autonomously based on this duration.

The starting conditions are indicated at the left side of the chart, with the vehicle connected and charging at its maximum rate of 3500[W].

At 2:25PM, a "Critical Peak" event was initiated. The EVSE executes this by limiting the charge current to 25% of the maximum, or a target of 25% of 22.5[A] = 5.625[A] = ~1440[W]. Because this is below the SAE 6[A] minimum, the actual value achieved in this scenario is 6[A] or ~By definition in the CEA-2045 standard, Critical Peak events are distinguished from Shed Events only in that they are intended to be used only a few times a year (in association with Critical Peak DR programs) and therefore may result in a more aggressive response by the end-device manufacturer. In the case of the Siemens EVSE, the response to a Critical Peak event is significantly more aggressive than the response to a regular curtailment/Shed event.

Immediately following the initiation of the event, the measured charging rate dropped to 1475[W] as indicated in Figure 2-10. At 2:40PM, 15 minutes after the event began, the charging level returned to 3500[W].

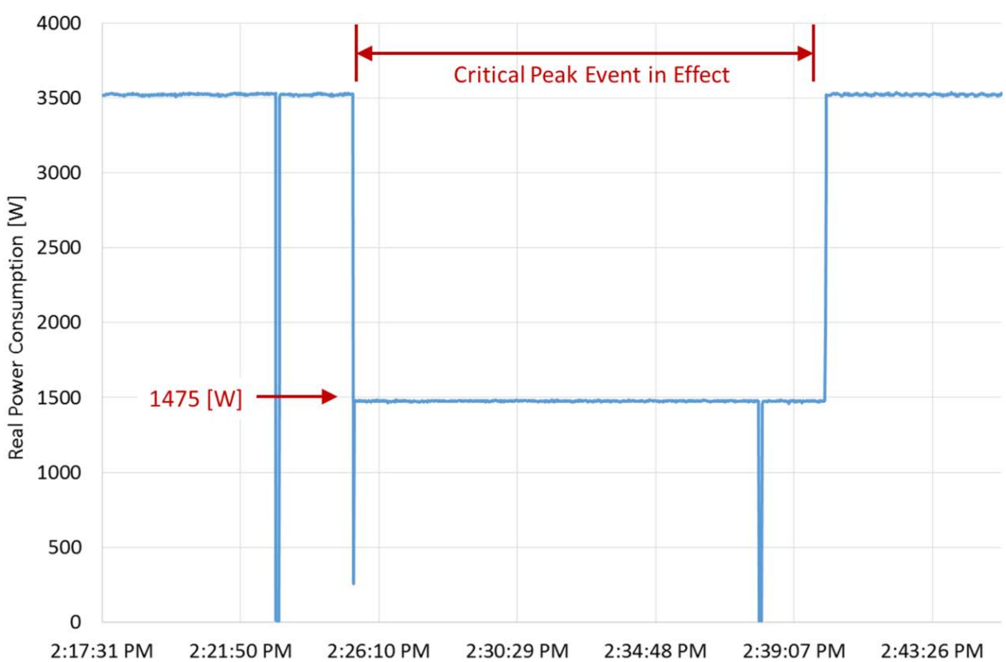

Figure 2-10
Critical Peak Event

During normal operation prior to the Critical Peak event, the EVSE was queried for its operating state and reported “Running Normal”. During the Critical Peak event, it was again queried and reported “Running Curtailed Grid”.

Grid Emergency Event

The results from the test of the EVSE’s “Grid Emergency” function are summarized in Figure 2-11. This test was conducted on July 27th, 2016. The Critical Peak event was sent with a 15 minute duration, and the EVSE was allowed to return to normal operation autonomously based on this duration.

The starting conditions are indicated at the left side of the chart, with the vehicle connected and charging at its maximum rate of 3500[W].

At 3:02PM, a “Grid Emergency” event was initiated. The Siemens EVSE executes this function by opening the contactor to turn off AC voltage to the vehicle, completely halting charging. Grid Emergency events are not intended for regular demand response uses, but rather to improve reliability by enabling home control systems or utilities to keep power on in emergency circumstances when generation is limited.

Immediately following the initiation of the event, the contactor in the EVSE was heard to operate and the measured charging rate dropped to 0[W] as indicated in Figure 2-11.

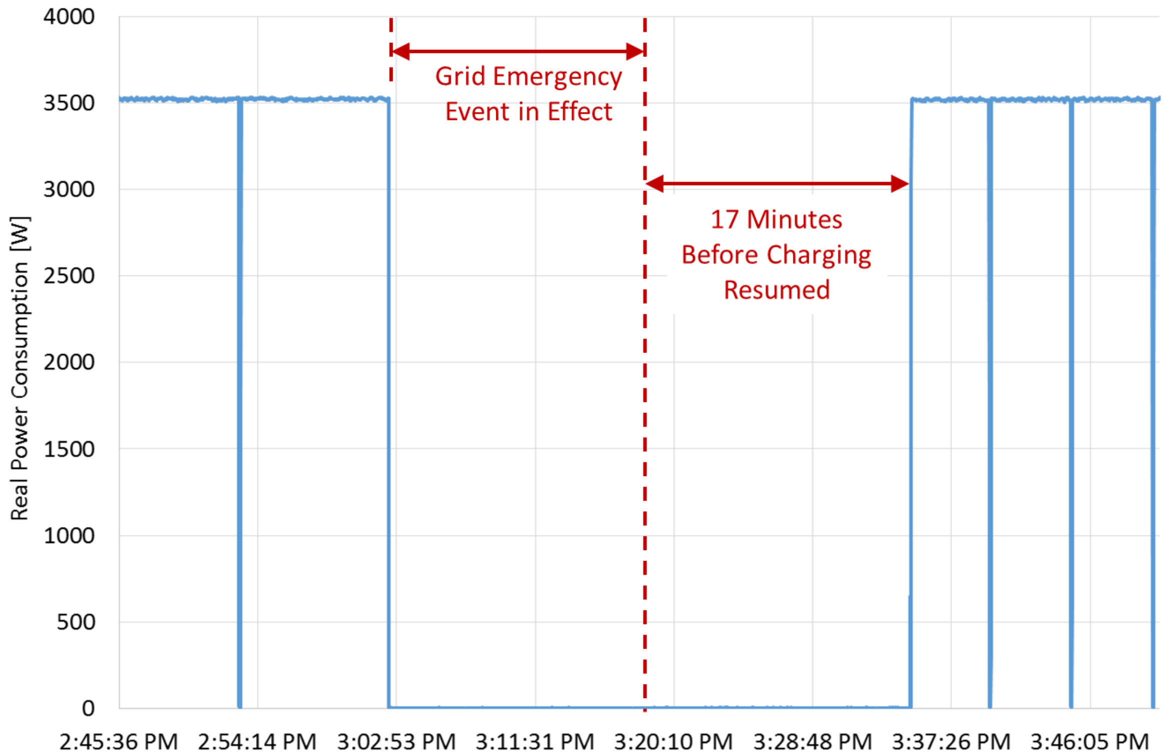

Figure 2-11
Grid Emergency Event

The Grid Emergency event ended at 3:17PM, 15 minutes after it began. This was detected and verified through the communication interface as the EVSE operating state changed from “Idle

Grid" to "Idle Normal". The vehicle, however, did not resume charging for another 17 minutes, at 3:34PM although its state of charge was only 50% as reported on the vehicle dashboard. It is not known why the vehicle delayed at this time. Various pauses and delays have been noted in EPRI testing of other vehicles as the charger in the vehicle ultimately determines if and when to turn on. This is a limitation which control systems must be aware-of in relation to EVSE utilization for up/down use cases. When charging did resume, it was at the full power charging level of 3500[W] as indicated in Figure 2-11. This is notably different than the behavior of the Shed and Critical Peak events which did not open the contactor and returned to full charge rate immediately at the end of the event.

During normal operation prior to the Grid Emergency event, the EVSE was queried for its operating state and reported "Running Normal". During the Grid Emergency event, it was again queried and reported "Running Curtailed Grid". During the delay immediately following the event, the EVSE reported "Idle Normal", and once charging resumed, it reported "Running Normal".

Variable Control

The Siemens EVSE was able to provide variable control by managing the duty cycle of the PWM signal on the pilot wire to the vehicle. As indicated in Figure 2-7, it was possible for this control to be effective over the range in which the vehicle was capable, between the 6[Amp] minimum set by the SAE J1772 standard and about 14.5[Amps] – the maximum for the vehicle used in this test. As illustrated in Figure 2-12, the SAE J1772 standard specifies a 1KHz (100mS period) signal on the pilot wire with a duty cycle that is linearly mapped from 6A at 10% to 48A at 80%, plus an allowance for accuracy.

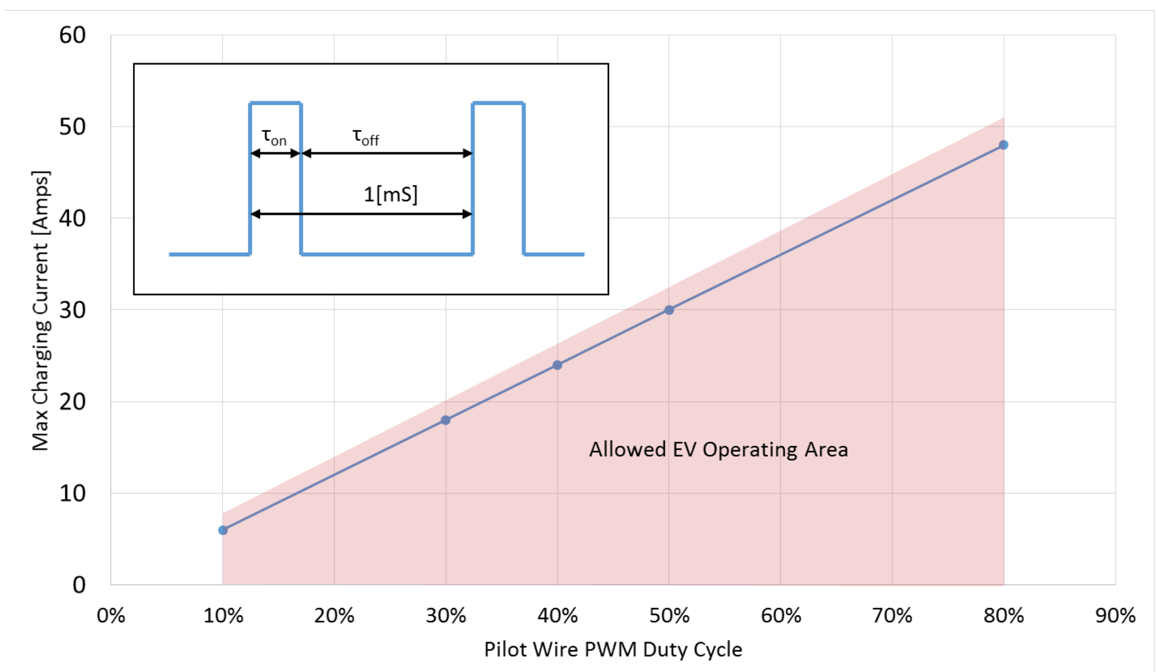

Figure 2-12
Relationship between Duty Cycle and Max Charging Current per SAE J1772

This capability was exposed using the CEA-2045 "Request Power Level" function which sends a percentage between 0% and 100% as a request for the end device to operate (to the extent possible) at that percentage of the maximum power level. Interpretation of this command is more complex for an EVSE because of two factors:

1. Depending on the wiring of the premises in which the EVSE is installed, the maximum allowed current may differ (this is controlled by a physical setting on the EVSE).
2. Different EVs have different maximum charging levels.

The results from the testing of the EVSE's variable control function are summarized in Figure 2-13. This test was conducted on July 28th, 2016. While the EV was charging, variable control settings were sent from 100% down to 30% in 10% steps (note: the fundamental CEA-2045 command has 1% resolution). Following this, the variable control settings were sent from 25% up to 75%, also in 10% steps.

The vehicle responded to the control signals immediately throughout the range of possible control. As indicated by the horizontal dashed lines, there appeared to be a discrete number of charging levels achieved, with the same levels occurring whether the control signals were rounded to 10% boundaries, as done during the ramping-down part of the test, or 5% boundaries as done during the ramping-up part. It was not possible during this test to probe the pilot wire PWM signal, so it is not known whether this quantification is a feature of the EVSE or the EV. In any case, it is allowed per the SAE standard because the pilot wire PWM signal is only a maximum that the EV must stay below, and a 7.5% overage tolerance is allowed.

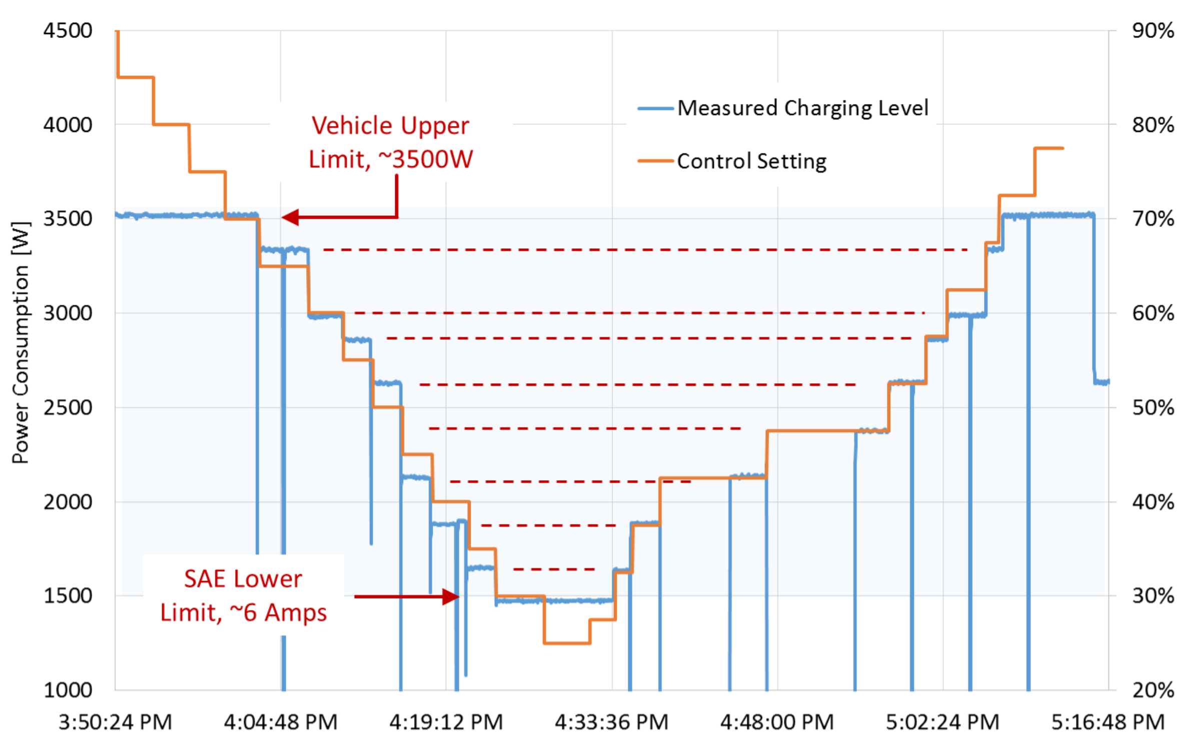

Figure 2-13
Variable Control

Energy Consumption Metering and Vehicle State of Charge

Throughout a period of testing that began at a low vehicle state of charge and ended near full charge, the EVSE was queried for the present power level and the cumulative energy consumption. The Siemens EVSE includes internal metering to support these status monitoring parameters. The results of the power measurement are shown in Figure 2-14.

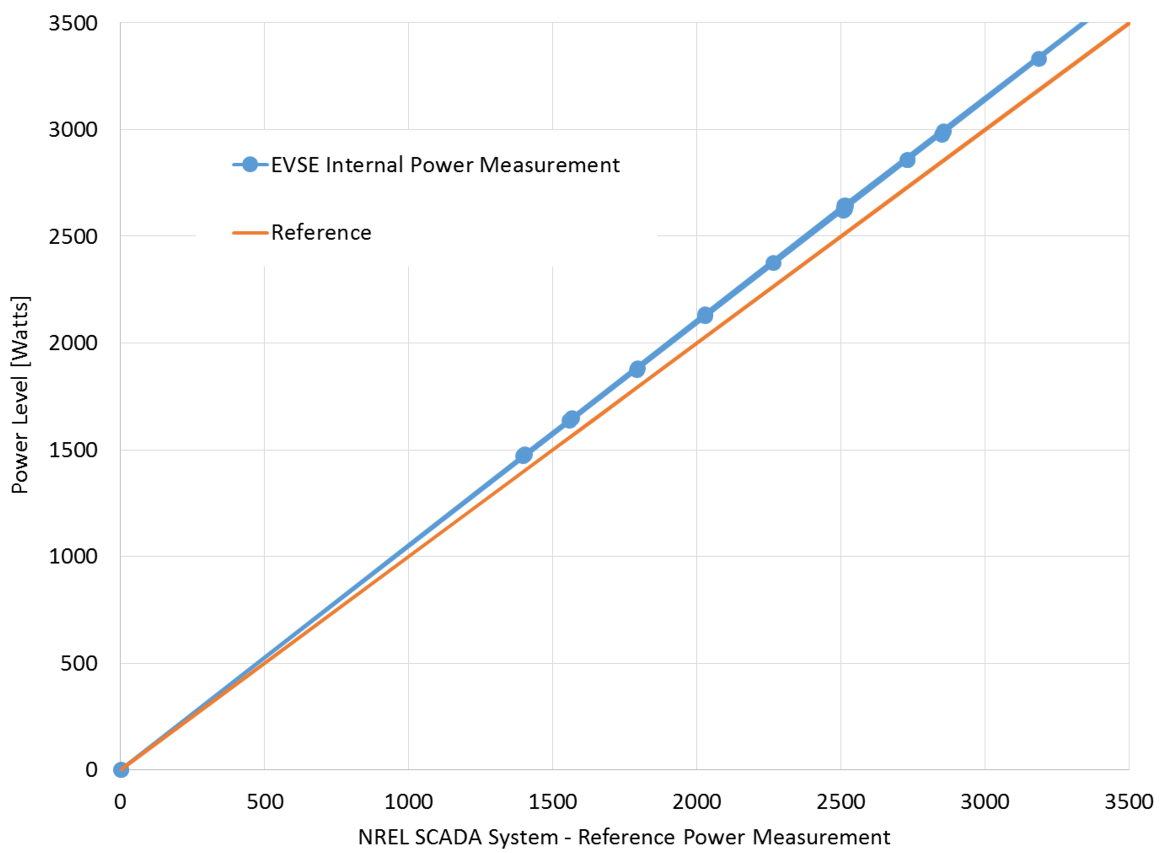

Figure 2-14
EVSE Power Measurement

This data reflects a ~3% scale difference between the EVSE measurement and the SCADA meter used in the NREL laboratory. This difference is unexplained as both are specified to be 0.5% accuracy and an additional power meter was not available at the time of testing.

The EVSE also calculates cumulative energy consumption. In Figure 2-15, this is compared to the vehicle dashboard state-of-charge readings. As indicated in the inlay photo, these dashboard readings had 10% resolution and were not constantly monitored for change. This data was collected over a charging cycle in which control actions were being taken that altered the rate of charging. The exact initial state of charge of the vehicle could not be determined, but was known to be low because after ~500[Wh] of charging the vehicle was displaying 10%. As indicated by the left and right vertical axes, this data would suggest ~9000[Wh] of charging to reach 100%.

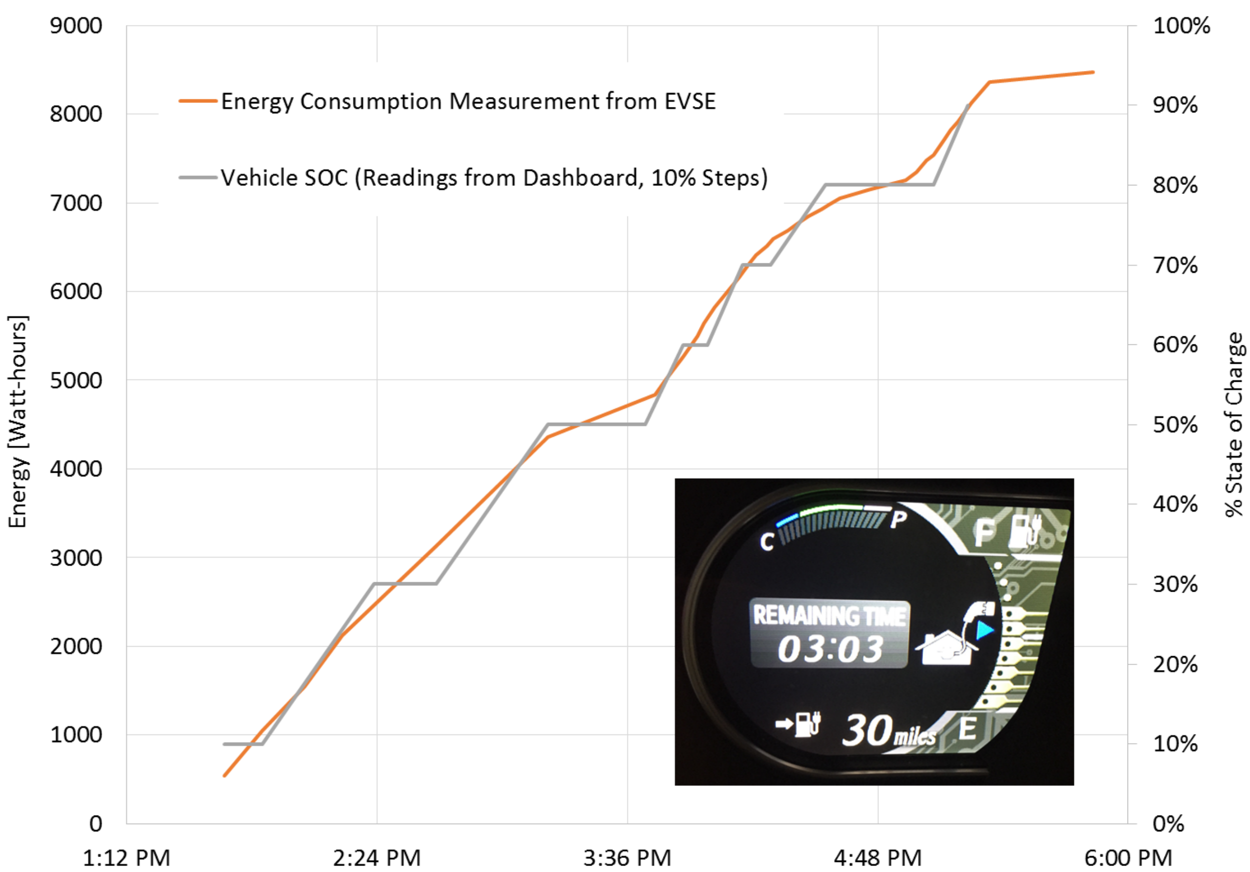

Figure 2-15
EVSE Energy Measurement

Consumer Override

Although not a functional requirement in terms of enabling more solar generation on the grid, consumer override is considered a required feature in order to ensure that the consumer is in control and to encourage program participation.

The results of the consumer override test are summarized in Figure 2-16. This test was performed on July 28th, 2016. The starting conditions can be seen at the left side of the chart. A Critical Peak event with 6 hour duration was initiated at 3:16PM in order to test the override function. In response, the EV charging level was curtailed to ~1500[W].

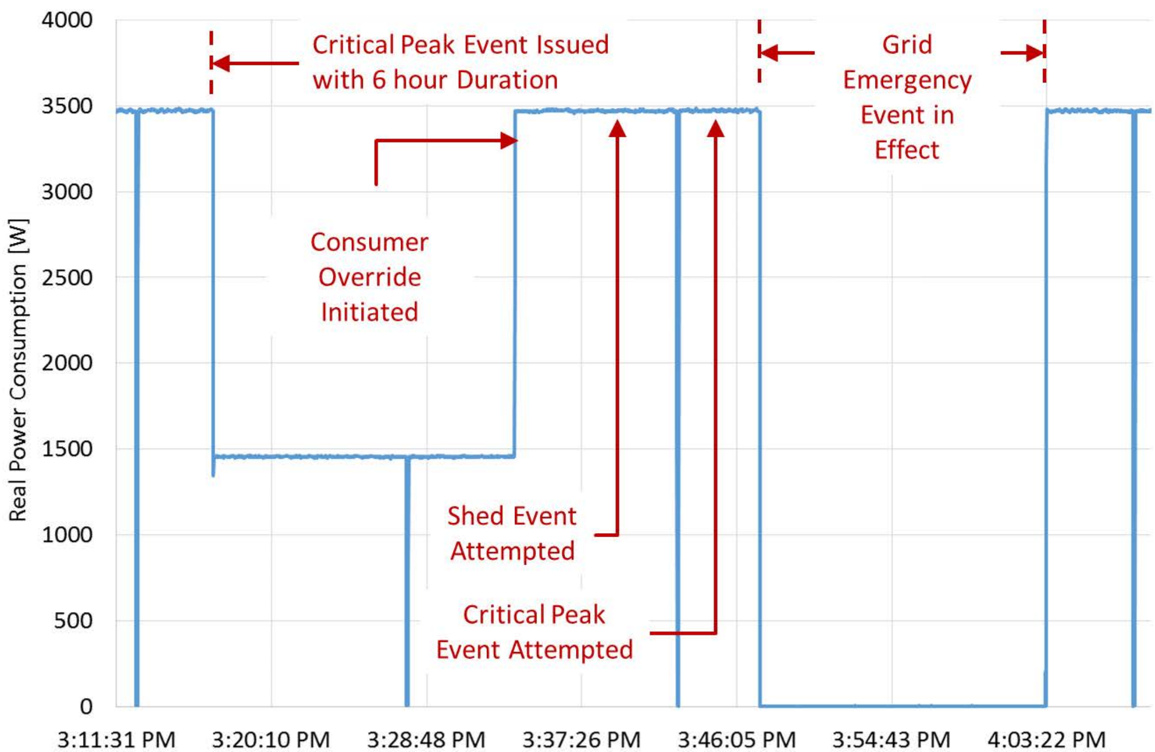

Figure 2-16
Consumer Override

At 3:33PM, a consumer override was initiated manually at the EVSE. This is done by pressing the "Consumer Override" button on the user interface as shown in Figure 2-8. When the Consumer Override was initiated, the EVSE immediately terminated the curtailment and operated normally, returning the vehicle charging rate to the maximum level. When this occurred, the EVSE performed an unsolicited notification over the communication interface as indicated in Figure 2-17.

Following the Consumer Override, three additional control events were attempted, as identified in Figure 2-16. By design, the EVSE did not respond to the Shed or Critical Peak events and returned Event Override notifications when each was sent. The "Grid Emergency" event was effective and the EVSE terminated EV charging by opening the contactor. This event type is intended for emergency/reliability uses and accordingly is the only event type that takes effect during override.

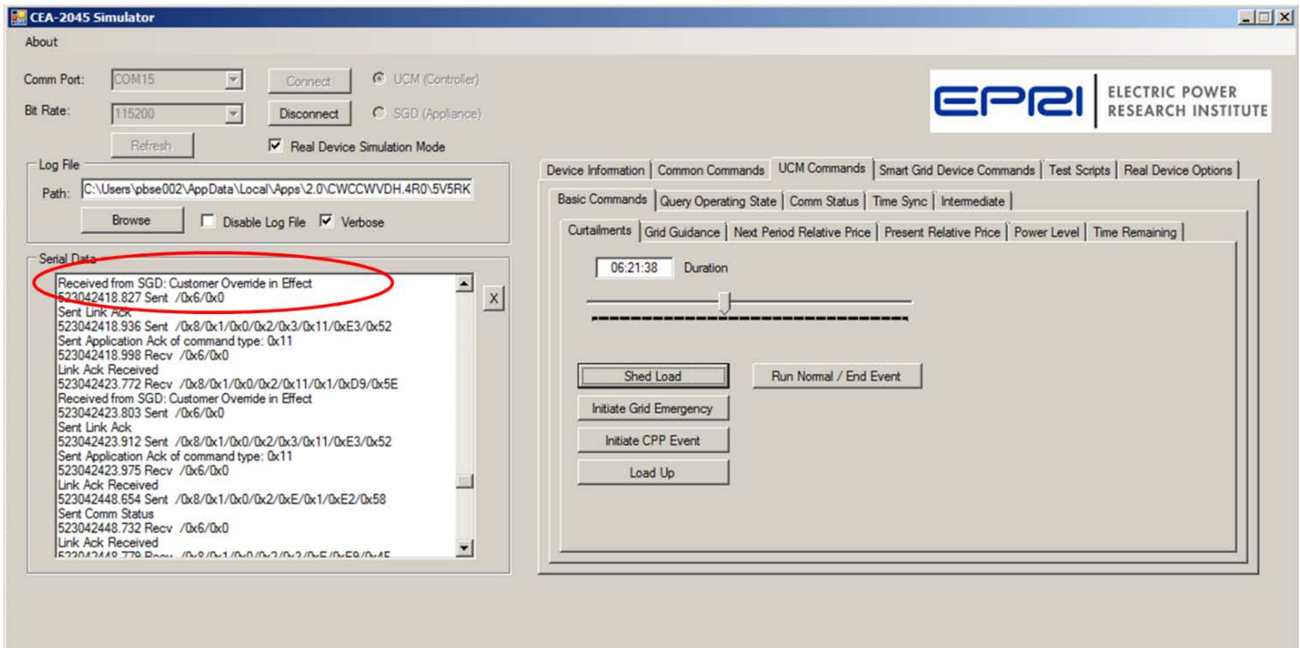

Figure 2-17
Communication Interface Showing Consumer Override

Loss of Communication

Although not a control function, this project included a verification that the EVSEs would return to normal operation in the event that communication to the remote control system is lost. In the CEA-2045 standard, communication modules are required to provide the end device with a communication status message at least once every 5 minutes. The EVSE design was such that if three periods pass (15 minutes) without successful notification, the unit will terminate active controls and return to normal operation.

In addition, the Siemens EVSE provided visual indication of the provided communication status on the display. As indicated in Figure 2-18, this included Good (Green), Bad (Yellow), and Lost (Red) indications.

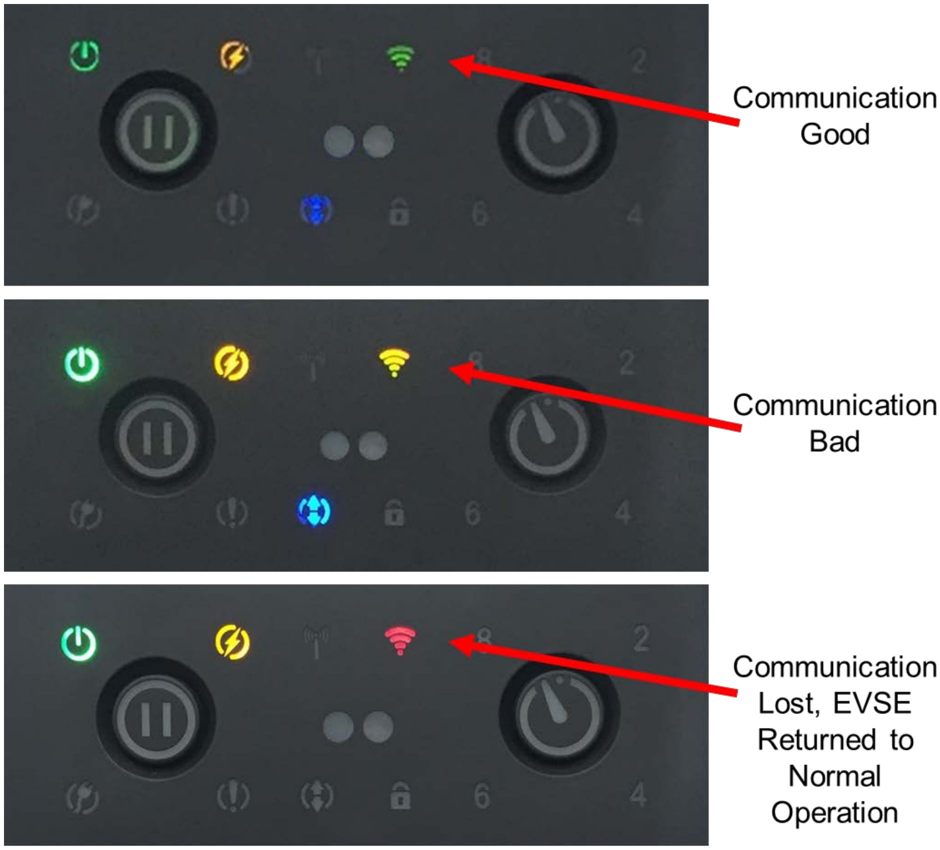

Figure 2-18
Siemens Communication Status Indicators

The results of the lab testing are shown in Figure 2-19. A Shed event was issued at 2:23PM with a 6 hour duration. At 2:28 PM, while this curtailment event was in effect, the EPRI software was used to change the recurring “Good Communication” message to a “Bad Communication” status. Immediately the EVSE changed the visual communication indicator to a blinking yellow. By design, this did not result in any change in the charging control. At 2:43 PM, the communication status messages were halted. At 2:58 PM, 15 minutes after the last communication status message was provided, the EVSE autonomously returned to normal operation, terminating the control event as shown in Figure 2-19.

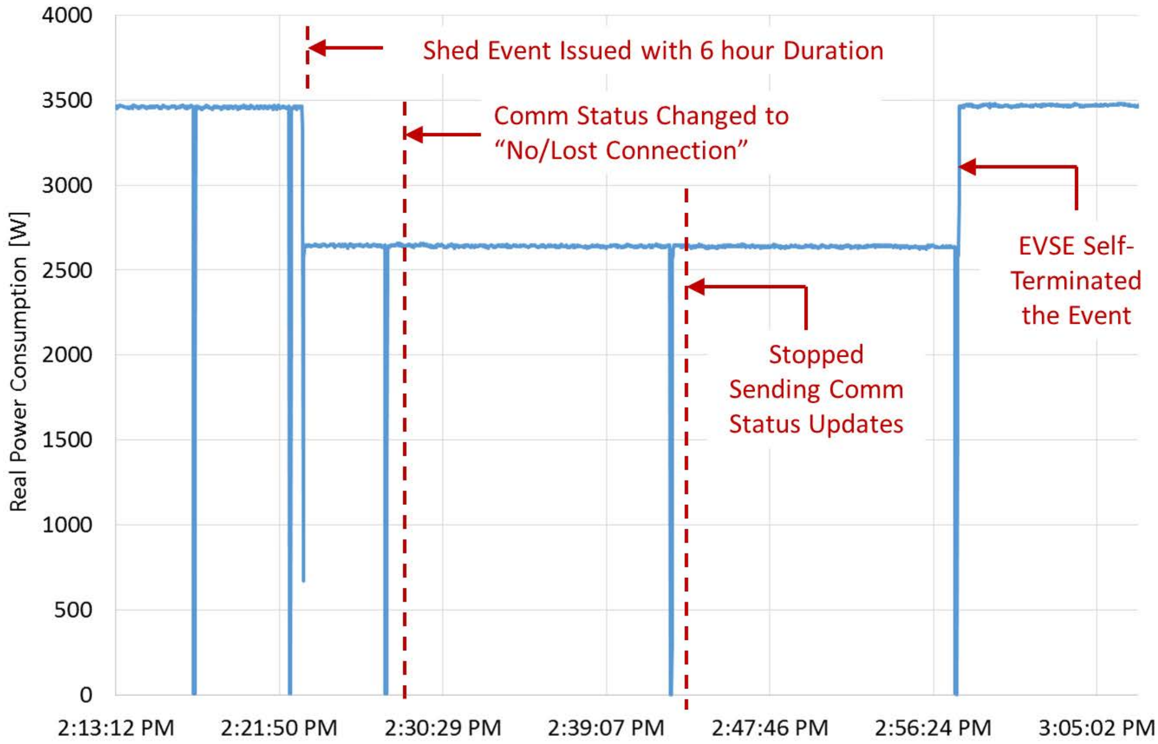

Figure 2-19
Communication Loss Test

Conclusions

The Siemens EVSEs passed all the tests and is able to perform the services required by this project.

The user interface was notably useful in the EVSE design, providing clear indications of the present conditions including the state of communication connectivity and control event. It also provided an easy-access control for event override.

The ability to achieve variable control from the EVSE was a significant accomplishment given that two-way communication with the vehicle was not possible. Variable functionality is valuable for enabling more renewable energy on the grid and is not possible with many end-device types such as single-speed HVAC and resistive water heaters.

The control responses for the EVSE are summarized in Table 2-1.

Table 2-1
Summary of EVSE Control Responses

Event	Maximum Charge Current Level	Comments
Normal Operation	22.5 [A]	Limit allowed by the EVSE as setup for this test (full capability of the device is 30A), but limited to ~14.5A by the particular EV used in this test.
Shed	11.25 [A]	Manufacturer's chosen limit, ½ the limit
Critical Peak	6 [A]	At the minimum limit as defined by the SAE.
Grid Emergency	Off	Disconnect during grid emergencies.
Variable	6 [A] to 22.5[A]	Continuously variable controls signals resulted in quantified variable charging steps for the EV under test.

Working together with the other smart end devices, these services can enable the grid to accommodate more renewable energy. Achieving this outcome will require communication and control systems that can successfully connect to end devices and manage their behavior in a cohesive fashion. Such systems may also have wide-area awareness, making it possible for devices in one location to act in such a way as to address issues elsewhere that are not locally visible.

The Siemens EVSE supported the functionality noted in this document using an open standard communication interface based on the CEA-2045 standard.

3002011757

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