

2015 Volkswagen e-Golf EV – VINs 2012, 2140, 5818, & 6525 Advanced Vehicle Testing –DC Fast Charging at Temperature Test Results



VEHICLE, ENERGY STORAGE SYSTEM, AND DCFC DETAILS¹

Vehicle Details

Base Vehicle: 2015 Volkswagen e-Golf EV
 Vehicle Type: BEV
 VINs: WVWPP7AU9FW902012; WVWPP7AU7FW902140;
 WVWKP7AUXFW905818; WVWKP7AU0FW906525

DCFC Details

Manufacturer: BTC Power
 Model/Type: EVFC-5-1-B-1-1-480/SAE CCS + CHAdeMO
 Rated DC Charge Power: 50 kW
 Rated DC Current²: 100 A

Energy Storage System Specifications

Manufacturer: Panasonic
 Type: Lithium-ion
 Rated Pack Energy/Capacity: 24.2 kWh/75.0 Ah
 Thermal Management: Passive - Air

Test Dates by VIN

| | 2012 | 2140 | 5818 | 6525 |
|-------|----------|----------|----------|----------|
| 0 °C | 12/01/15 | 12/11/15 | 12/22/15 | 01/05/16 |
| 25 °C | 12/03/15 | 12/04/15 | 12/29/15 | 01/07/16 |
| 50 °C | 12/08/15 | 12/09/15 | 01/06/16 | 01/13/16 |

TEST RESULTS SUMMARY

| Test Temp. (°C) | Total Charge Duration (hh:mm:ss) | End of Charge Range (mi) | Total DC Charge Energy (kWh) | Initial Charge Start/End SOC ³ (%) | Top-Off Charge Start/End SOC ³ (%) | Initial/Top-Off Charge Avg. Power (kW) | ESS ΔT ⁴ (°C) | ESS Thermal Regulation Energy ⁵ (kWh) |
|--|----------------------------------|--------------------------|------------------------------|---|---|--|--------------------------|--|
| VIN 2012 - Beginning-of-Test (at 4,677 miles)⁶ | | | | | | | | |
| 0 °C | 01:02:20 | 90 | 21.30 | 6.8 / 92.4 | 92.4 / 92.8 | 20.9 / 5.9 | 1.6 | N/A |
| 25 °C | 00:54:27 | 104 | 22.16 | 6.0 / 93.2 | 93.2 / 94.0 | 25.6 / 3.0 | 0.4 | N/A |
| 50 °C | 00:54:17 | 46 | 10.06 | 6.4 / 47.2 | 47.2 / 48.0 | 11.3 / 6.3 | 0.1 | N/A |
| Middle-of-Test | | | | | | | | |
| 0 °C | | | | | | | | |
| 25 °C | | | | | | | | |
| 50 °C | | | | | | | | |
| End-of-Test | | | | | | | | |
| 0 °C | | | | | | | | |
| 25 °C | | | | | | | | |
| 50 °C | | | | | | | | |
| VIN 2140- Beginning-of-Test (at 5,948 miles)⁶ | | | | | | | | |
| 0 °C | 00:56:15 | 95 | 20.94 | 6.4 / 90.4 | 90.4 / 91.2 | 22.8 / 8.3 | 2.0 | N/A |
| 25 °C | 00:43:48 | 105 | 21.37 | 4.8 / 89.2 | 89.2 / 90.0 | 30.0 / 8.9 | 2.4 | N/A |
| 50 °C | 00:32:27 | 28 | 6.41 | 5.6 / 30.4 | 30.4 / 32.0 | 12.0 / 9.9 | -0.4 | N/A |
| Middle-of-Test | | | | | | | | |
| 0 °C | | | | | | | | |
| 25 °C | | | | | | | | |
| 50 °C | | | | | | | | |
| End-of-Test | | | | | | | | |
| 0 °C | | | | | | | | |
| 25 °C | | | | | | | | |
| 50 °C | | | | | | | | |

ADVANCED VEHICLE TESTING ACTIVITY

| Test Temp. (°C) | Total Charge Duration (hh:mm:ss) | End of Charge Range (mi) | Total DC Charge Energy (kWh) | Initial Charge Start/End SOC ³ (%) | Top-Off Charge Start/End SOC ³ (%) | Initial/Top-Off Charge Avg. Power (kW) | ESS ΔT ⁴ (°C) | ESS Thermal Regulation Energy ⁵ (kWh) |
|--|----------------------------------|--------------------------|------------------------------|---|---|--|--------------------------|--|
| VIN 5818 - Beginning-of-Test (at 7,625 miles)⁶ | | | | | | | | |
| 0 °C | 00:49:55 | 78 | 20.55 | 12.4 / 94.4 | 94.4 / 94.8 | 25.4 / 4.4 | 2.4 | N/A |
| 25 °C | 00:48:15 | 101 | 21.69 | 4.8 / 92.0 | 92.0 / 92.4 | 27.7 / 4.4 | 2.5 | N/A |
| 50 °C | 01:15:09 | 68 | 17.52 | 5.2 / 68.8 | 68.8 / 77.2 | 15.1 / 9.2 | 1.3 | N/A |
| Middle-of-Test | | | | | | | | |
| 0 °C | | | | | | | | |
| 25 °C | | | | | | | | |
| 50 °C | | | | | | | | |
| End-of-Test | | | | | | | | |
| 0 °C | | | | | | | | |
| 25 °C | | | | | | | | |
| 50 °C | | | | | | | | |
| VIN 6525 - Beginning-of-Test (at 8,459 miles)⁶ | | | | | | | | |
| 0 °C | 00:51:03 | 78 | 20.29 | 11.6 / 94.8 | 94.8 / 94.8 | 24.0 / -0.4 | 2.6 | N/A |
| 25 °C | 00:48:06 | 103 | 20.45 | 10.4 / 95.2 | 95.2 / 95.2 | 26.7 / 0.0 | 1.9 | N/A |
| 50 °C | 01:03:27 | 43 | 14.34 | 7.2 / 67.6 | N/A | 14.2 / -0.1 | 1.8 | N/A |
| Middle-of-Test | | | | | | | | |
| 0 °C | | | | | | | | |
| 25 °C | | | | | | | | |
| 50 °C | | | | | | | | |
| End-of-Test | | | | | | | | |
| 0 °C | | | | | | | | |
| 25 °C | | | | | | | | |
| 50 °C | | | | | | | | |

Test Results Analysis

DC fast charging at temperature testing includes tests that measure the charge duration, energy transfer, and energy used to thermally regulate the energy storage system (ESS) for charge events at 0, 25 and 50 °C.⁷ The objective of this testing is to provide analysis about the effects of ambient temperature on DC fast charge-capable vehicles. These tests were performed as part of the US Department of Energy Advanced Vehicle Testing Activity, which is conducted by Idaho National Laboratory and Intertek Center for Evaluation of Clean Energy Technology (CECET).

Test Results: Energy and SOC

Figures 1a, 1b, and 1c show the energy transferred to each vehicle and the change in state of charge (SOC) over the duration of each charge event for each of the specified temperatures. Most DC fast charge events consist of an initial charge event and a top-off charge event.^{8,9} VIN 6525 would not accept a top-off charge at any temperature. For the other vehicles, the end of the initial charge is denoted by a dashed oval. Many vehicle manufacturers report the time required for a charge of the ESS to 80% SOC as being 30 minutes; for VIN 2012, the SOC_s recorded at the 30-minute mark for the 0, 25, and 50 °C tests were 46.0%, 72.8%, and 30.0%, respectively. For VIN 2140, the SOC_s recorded at the 30-minute mark for the 0, 25, and 50 °C tests were 48.8%, 71.2%, and 30.4%, respectively. For VIN 5818, the SOC_s recorded at the 30-minute mark for the 0, 25, and 50 °C tests were 76.0%, 73.2%, and 40.8%, respectively. For VIN 6525, the SOC_s recorded at the 30-minute mark for the 0, 25, and 50 °C tests were 69.2%, 79.6%, and 41.2%, respectively.

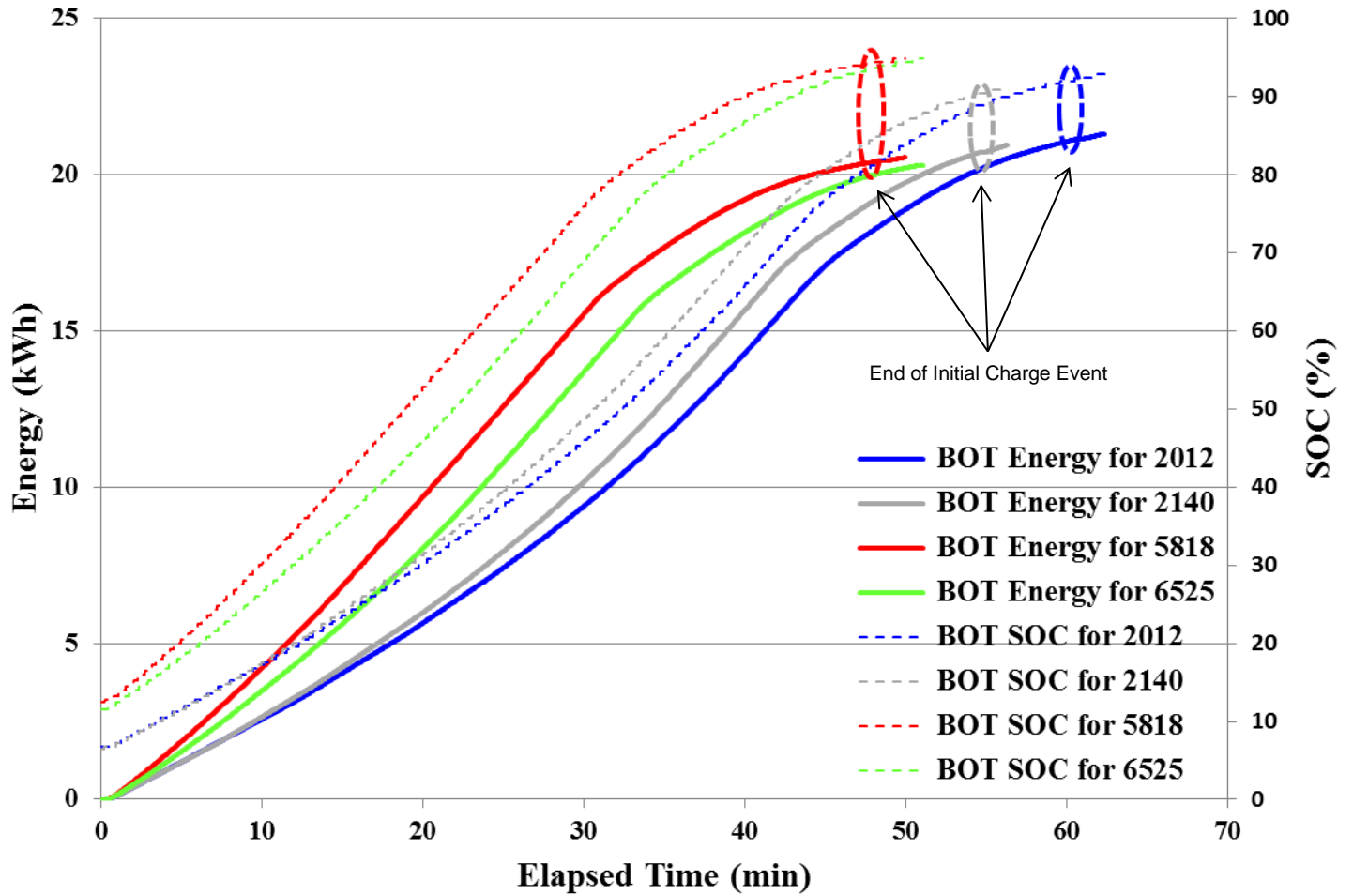


Figure 1a. 0 °C charge energy and SOC versus time

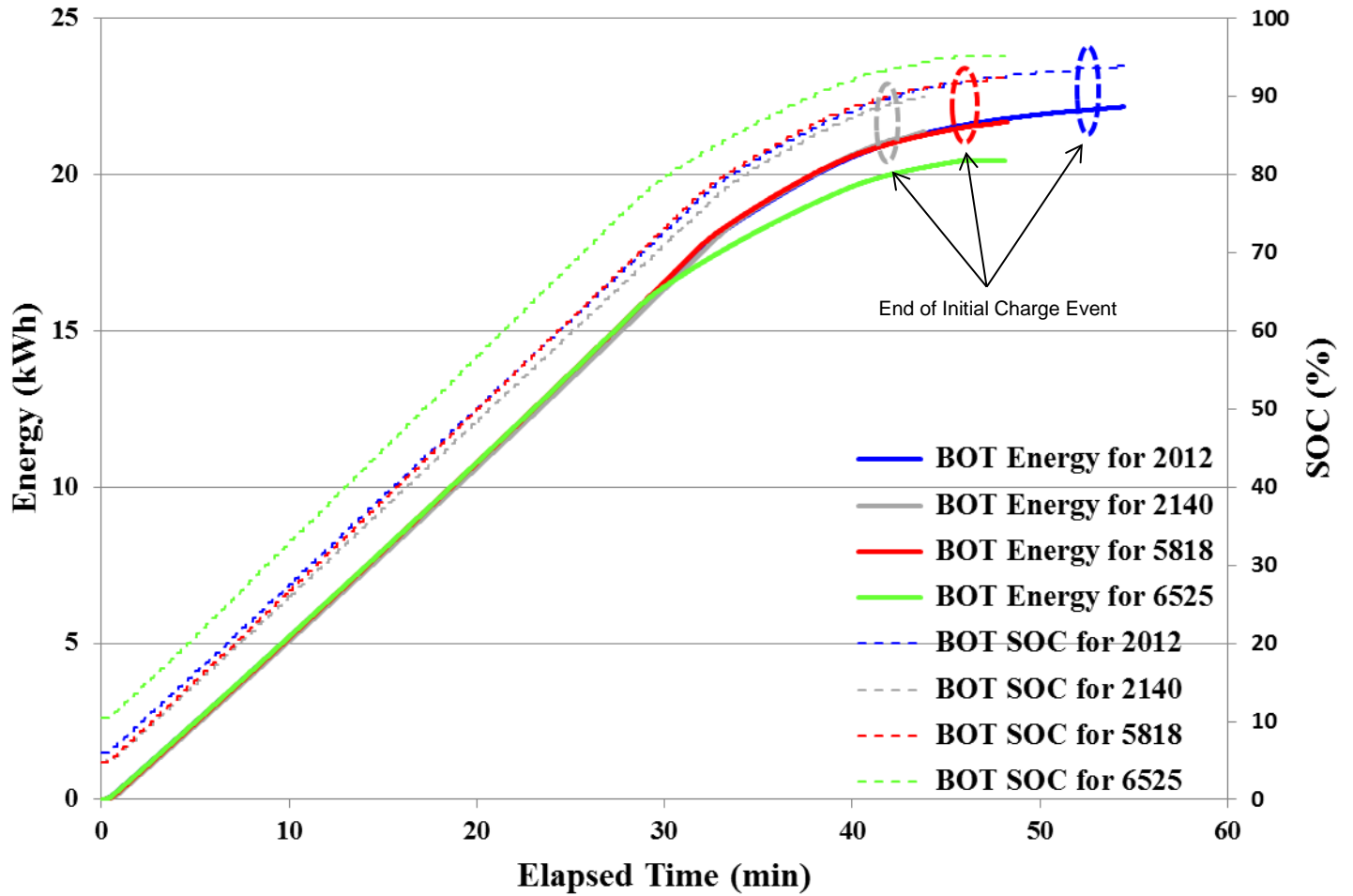


Figure 1b. 25 °C charge energy and SOC versus time

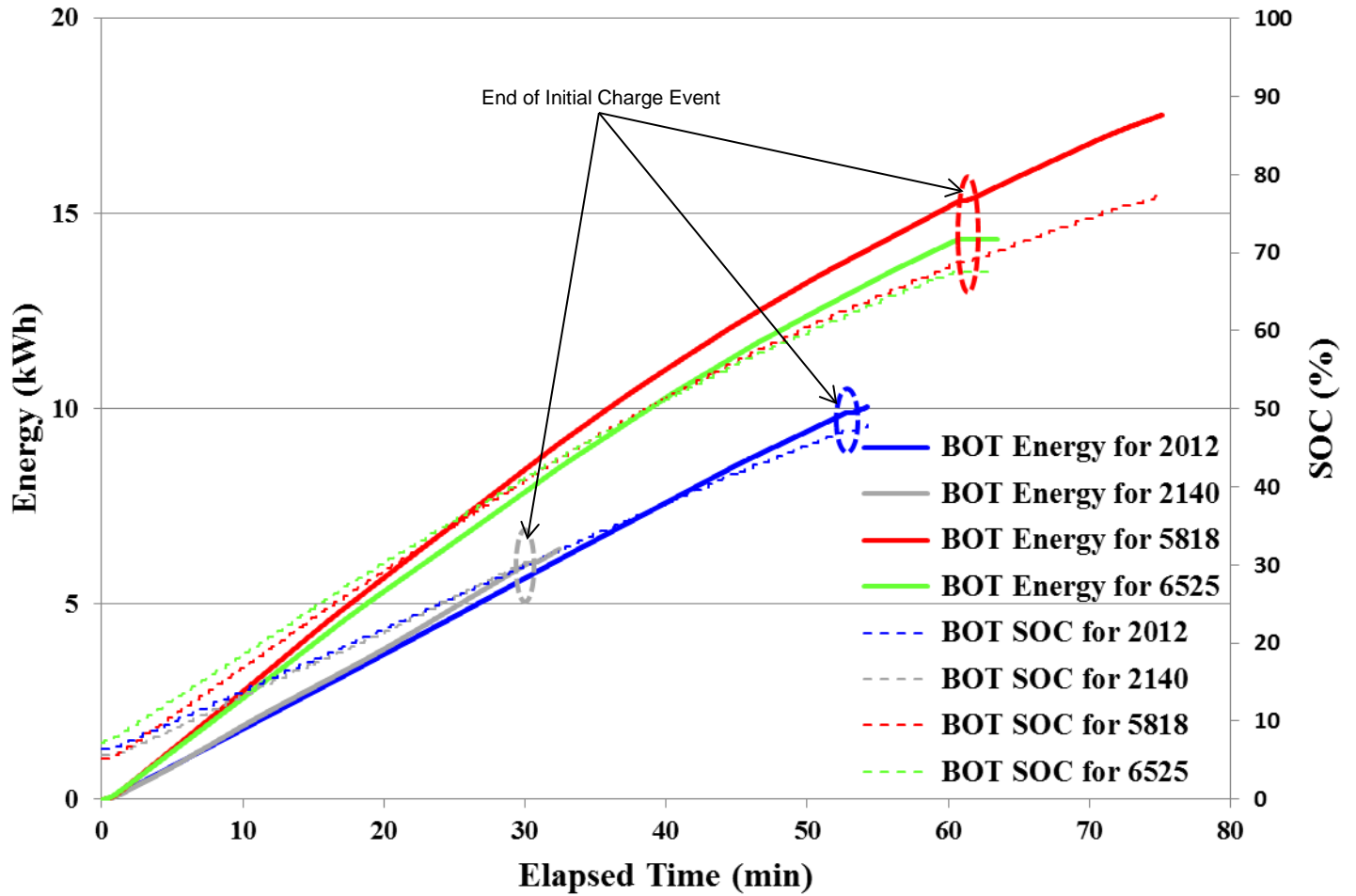


Figure 1c. 50 °C charge energy and SOC versus time

Test Results: Temperatures

Tables 1, 2, 3, and 4 show the initial and maximum enclosure temperatures of each vehicle’s ESS during charging events.

Table 1. VIN 2012 ESS enclosure temperature during test

| Test Temperature (°C) | ESS Initial Temp. (°C) | ESS Final Temp. (°C) | ESS Maximum Temp. (°C) |
|-----------------------|------------------------|----------------------|------------------------|
| 0 °C | -1.5 | 0.1 | 0.1 |
| 25 °C | 26.6 | 27.0 | 27.8 |
| 50 °C | 49.9 | 50.0 | 50.3 |

Table 2. VIN 2140 ESS enclosure temperature during test

| Test Temperature (°C) | ESS Initial Temp. (°C) | ESS Final Temp. (°C) | ESS Maximum Temp. (°C) |
|-----------------------|------------------------|----------------------|------------------------|
| 0 °C | -0.8 | 1.2 | 1.4 |
| 25 °C | 26.1 | 28.5 | 28.6 |
| 50 °C | 49.9 | 49.6 | 50.1 |

Table 3. VIN 5818 ESS enclosure temperature during test

| Test Temperature (°C) | ESS Initial Temp. (°C) | ESS Final Temp. (°C) | ESS Maximum Temp. (°C) |
|-----------------------|------------------------|----------------------|------------------------|
| 0 °C | 1.3 | 3.8 | 3.9 |
| 25 °C | 23.4 | 25.9 | 25.9 |
| 50 °C | 47.3 | 48.5 | 48.5 |

Table 4. VIN 6525 ESS enclosure temperature during test

| Test Temperature (°C) | ESS Initial Temp. (°C) | ESS Final Temp. (°C) | ESS Maximum Temp. (°C) |
|-----------------------|------------------------|----------------------|------------------------|
| 0 °C | 0.1 | 2.7 | 2.9 |
| 25 °C | 25.9 | 27.8 | 27.9 |
| 50 °C | 47.6 | 48.3 | 48.5 |

Test Results: Charge Power^{10, 11}

Figures 2a, 2b, and 2c show the power at which each vehicle's ESS was being charged for each of the specified temperatures. As before, the end of the initial charge event is denoted by a dashed oval.

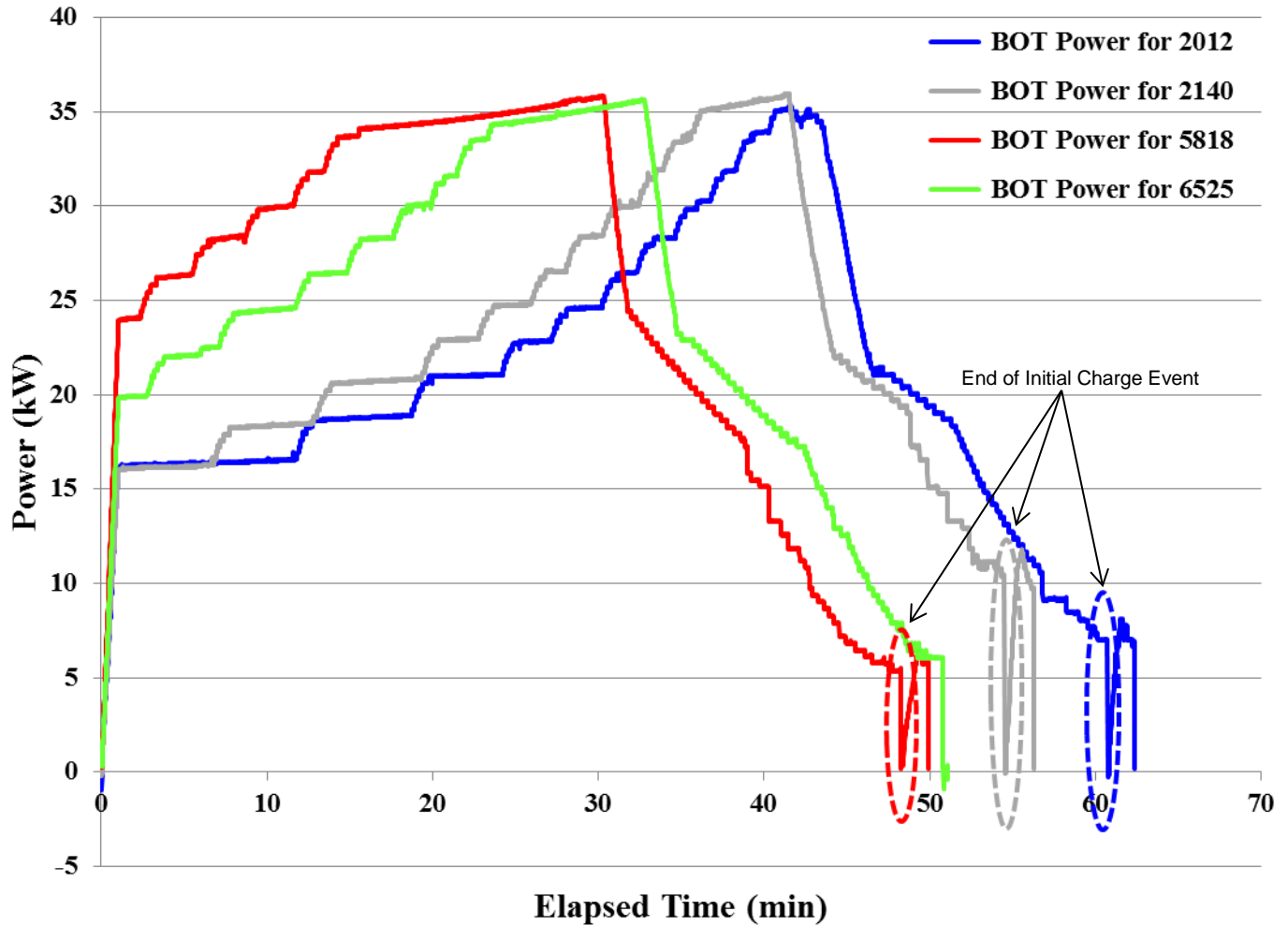


Figure 2a. 0 °C charge power profiles

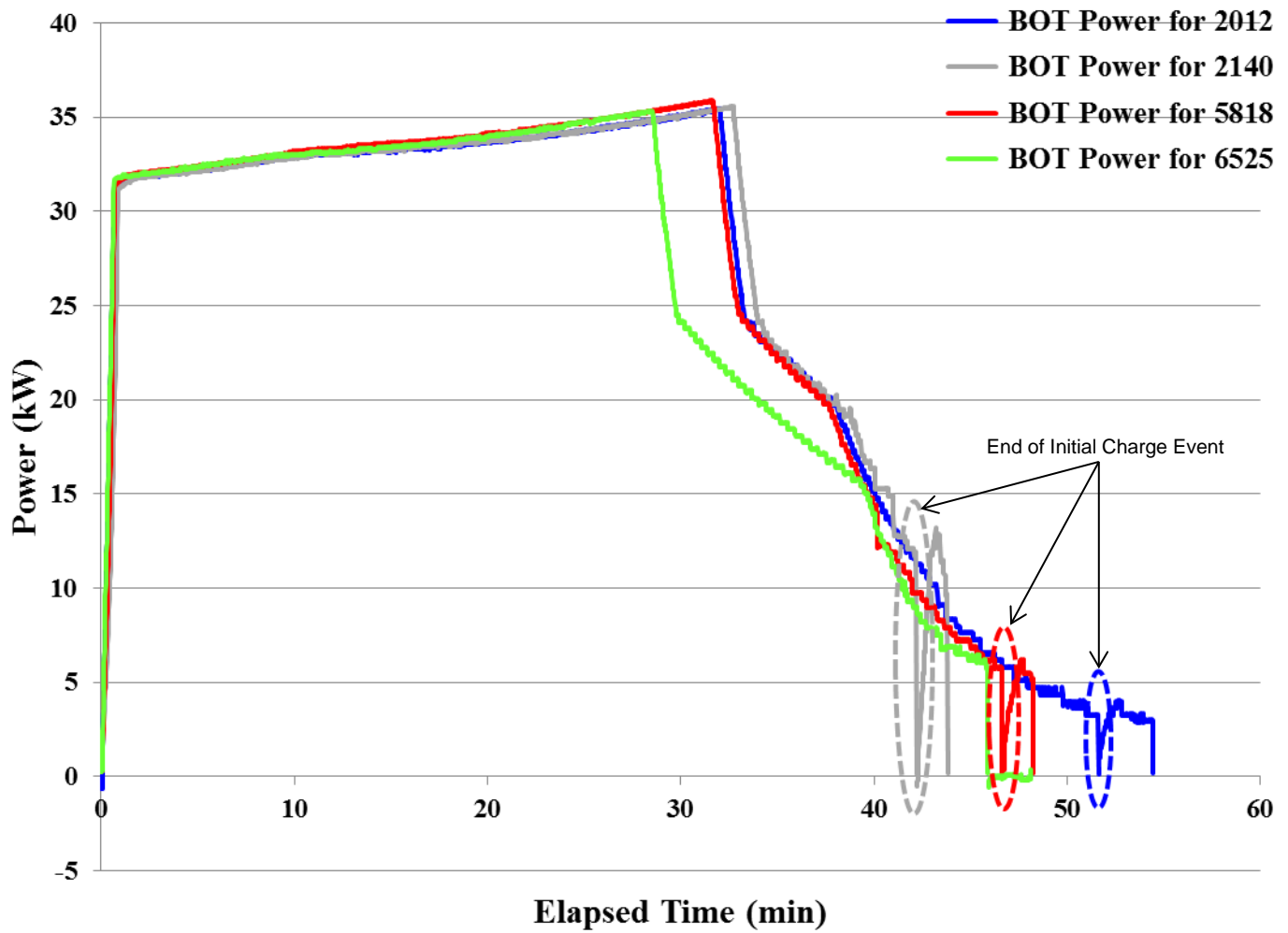


Figure 2b. 25 °C charge power profiles

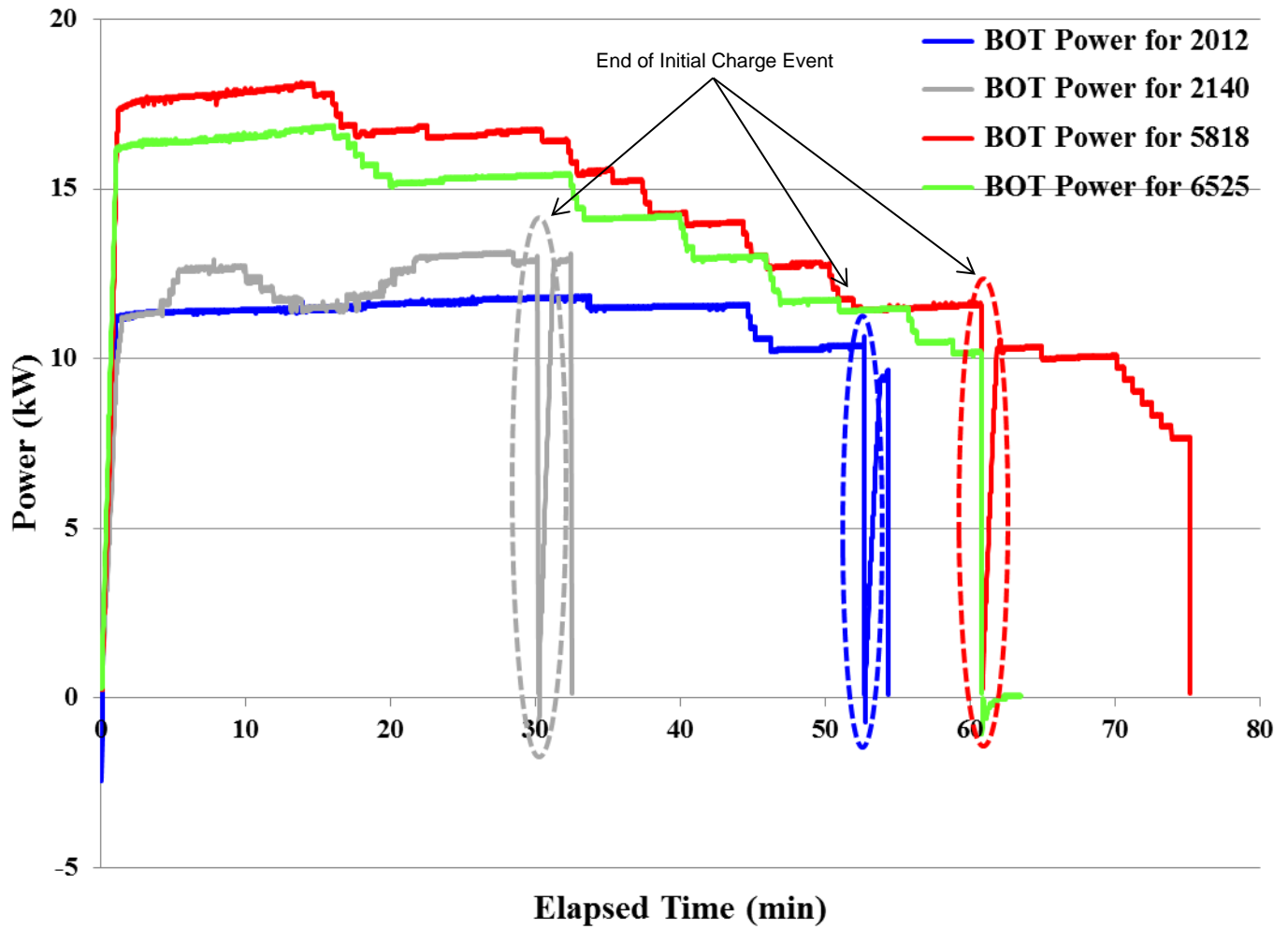


Figure 2c. 50 °C charge power profiles

NOTES:

- Vehicle, ESS, and DCFC details were either supplied by the manufacturer or derived from a literature review.
- The BTC DCFC has a maximum current output of 100 A. The BTC DCFC shuts down after 60 minutes regardless of the presence of a stop signal from the vehicle.
- The ESS SOC is recorded from the vehicle controller area network (CAN) bus. The SOC displayed on the dashboard is also recorded for comparison and corroboration when available. In the case of the Chevrolet Spark EV, the CAN SOC correlates with the SOC revealed by a diagnostic scan tool. Refer to Note 8 for details concerning top-off charge events.
- The “ESS ΔT” is the difference in the temperature of the ESS enclosure between start and end of test. This parameter is calculated using the vehicle CAN message for battery temperature when available. When the CAN message is not available, the ESS enclosure temperature is measured by placing a thermocouple on the top of the battery pack enclosure. In the case of the Volkswagen e-Golf EV, ESS enclosure temperatures were obtained via thermocouples placed on the side of the enclosure.
- The thermal regulation load is an approximate calculation of the amount of energy used by the vehicle to regulate ESS temperature, where applicable. This is calculated by subtracting the amount of energy into the ESS from the amount of energy output by the DCFC; the calculated value also includes resistive and conversion electrical losses. In the case of the Volkswagen e-Golf, there is no active thermal regulation. It is possible that the energy values noted for tests are due to parasitic losses or powering of the vehicle fast charging system. There are three possibilities for how the onboard vehicle electronics receive power during a fast charge: 1) 12 V interface on the CCS charger, 2) DC-to-DC converter steps high voltage down to 12 V, or 3) the system could be powered directly from the 12 V battery of the vehicle.
- Each fast charge-capable vehicle is chamber tested three times over the course of its test life. Under normal circumstances for EVs, the temperature chamber testing will take place at the same mileage target as the ESS Beginning of Test (BOT) test at 400 miles. The Middle of Test (MOT) takes place at the same mileage target as the ESS Interim Component Durability 3 (ICD3) test that is conducted at 24,000 miles. Finally, the End of Test (EOT) is conducted at the same mileage target as the ESS EOT test that is conducted at 36,000 miles. In the case of the Volkswagen e-Golf EV, the procurement of an SAE CCS fast charger was made after the vehicles had reached BOT mileage.
- Each test consists of a soak period necessary to ensure the vehicle ESS is at the target test temperature; the soak period is a minimum of 21 hours.
- One top-off charge is conducted per test regardless of the ESS SOC reading at the end of the initial and top-off charge events. The battery management system (BMS) determines the stopping point of the initial and top-off charge events, assuming the charge takes less than 1 hour. VIN 6525 would not accept a top-off charge at any temperature. The dashboard Vehicle Energy Indicator (VEI) for each vehicle at the start/end of each test was as follows:

VIN 2012

0 °C: 0.00 / 1.00

25 °C: 0.00 / 1.00

50 °C: 0.00 / 0.48

VIN 2140:

0 °C: 0.00 / 0.92

25 °C: 0.00 / 0.92

50 °C: 0.00 / 0.26

VIN 5818:

0 °C: 0.00 / 1.00

25 °C: 0.00 / 0.94

50 °C: 0.00 / 0.79

VIN 6525:

0 °C: 0.00 / 0.99

25 °C: 0.00 / 0.99

50 °C: 0.00 / 0.62

- Time (in seconds) between the end of the initial charge and beginning of the top-off charge is collected for each test. This delay has not been included in Figure 1 and Figure 2.

VIN 2012:

0 °C: 169 s

25 °C: 123 s

50 °C: 102 s

VIN 2140:

0 °C: 71 s

25 °C: 229 s

50 °C: 431 s

VIN 5818:

0 °C: 78 s

25 °C: 79 s

50 °C: 189 s

VIN 6525:

0 °C: N/A

25 °C: N/A

50 °C: N/A

- Maximum charge power for initial and top-off charges:

VIN 2012:

0 °C: 35.3 / 8.1 kW

25 °C: 35.5 / 4.0 kW

50 °C: 11.9 / 9.7 kW

VIN 2140:

0 °C: 36.0 / 11.8 kW

25 °C: 35.6 / 13.2 kW

50 °C: 13.2 / 13.1 kW

VIN 5818:

0 °C: 35.9 / 6.2 kW

25 °C: 35.9 / 6.2 kW

50 °C: 18.1 / 10.6 kW

VIN 6525:

0 °C: 35.7 / N/A kW

25 °C: 35.4 / N/A kW

50 °C: 16.9 / N/A kW

- Voltage at end of initial charge / voltage at end of top-off charge / maximum charge voltage / voltage at initial current drop off:

VIN 2012:

0 °C: 356.1 / 356.1 / 357.5 / 350.0 V

25 °C: 356.1 / 357.1 / 357.2 / 349.8 V

50 °C: 323.7 / 323.5 / 325.3 / 321.3 V

VIN 2140:

0 °C: 355.6 / 355.8 / 357.5 / 352.0 V

25 °C: 354.4 / 354.7 / 356.3 / 350.6 V

50 °C: 319.6 / 319.8 / 321.7 / 310.6 V

VIN 5818:

0 °C: 356.7 / 356.8 / 357.8 / 351.9 V

25 °C: 356.5 / 356.6 / 357.5 / 351.3 V

50 °C: 337.3 / 343.5 / 344.5 / 318.4 V

VIN 6525:

0 °C: 355.3 / N/A / 356.4 / 349.9 V

25 °C: 353.9 / N/A / 355.5 / 346.8 V

50 °C: 333.6 / N/A / 335.2 / 318.3 V