Recent Results from INL's EV Project Analysis and Advanced Vehicle Testing

GITT meeting
2/11/2015

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Idaho National Laboratory

Outline

- Plug-In electric vehicle gasoline tax revenue analysis
- Corridor DC fast charger usage on the West Coast Electric Highway
- Chevy Volt charging system power quality testing
- Chevy Volt on-road cold weather testing

Plug-In Electric Vehicle Gas Tax Revenue Analysis

- Plug-in electric vehicles do a portion or all of their driving using electricity from the grid
- Drivers are not purchasing gas to drive those miles and are not paying road tax.
- INL electric vehicle miles traveled (eVMT) analysis from over 21,000 privately-owned PEVs enables estimation of lost gas tax revenue
  - Nissan Leaf, Honda Fit, Ford Focus EV
  - Chevrolet Volt, Ford Fusion Energi, Ford Cmax Energi, Honda Accord PHEV, Toyota Prius Plug-in
  - Information was previously published on VMT and eVMT

Annual eVMT by Vehicle Type

BEV

	Nissan LEAF	Ford Focus Electric	Honda Fit EV
Vehicles	4,039	2,193	645
eVMT	9,697	9,548	9,680

- **Weighted average annual eVMT per BEV = 9,648**

PHEV/EREV

	Chevorlet Volt	Ford CMax Energi	Ford Fusion Energi	Honda Accord PHEV	Toyota Prius Plug-in
Vehicles	1,867	5,368	5,803	189	1,523
eVMT	9,112	4,069	4,337	3,336	2,484

- **Weighted average annual eVMT per PHEV = 4,640**

Fuel Economy of Comparative Gasoline Vehicles

PEV Models	Comparative ICE Model	EPA Combined Fuel Economy (MPG)
Nissan Leaf	2014 Nissan Versa	35
Chevrolet Volt	2014 Chevrolet Cruze	30
Ford Focus BEV	2014 Ford Focus	31
Ford CMax Energi	2014 Ford Fiesta	34
Ford Fusion Energy	2014 Ford Fusion	28
Honda Fit EV	2014 Honda Civic HEV	30
Honda Accord PHEV	2014 Honda Accord	29
Toyota Prius Plug-in	2014 Toyota Prius	50
	Average	**33.4**

Estimated Equivalent Annual Fuel Tax for PEVs

- ICE Vehicles
  - Idaho gasoline fuel tax is $0.25/gal
  - The national average fuel tax is $0.24/gal
  - At 33.4 MPG, average vehicle pays $0.007485 in fuel tax per mile
- BEVs
  - Average 9,648 annual eVMT
  - Equivalent BEV fuel tax = **$72.22 annually**
- PHEVs
  - Average 4,640 annual eVMT
  - Equivalent PHEV fuel tax = **$34.73 annually**

To access the full report on the INL website, go to:

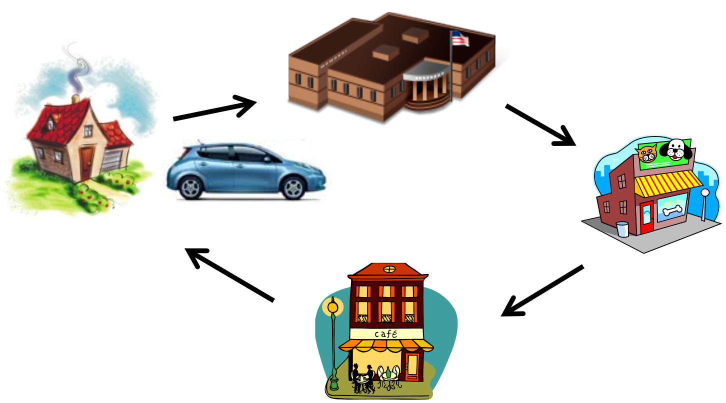
avt.inl.gov/pdf/phev/PEVandPHEVeVMTforIAHD.pdf

INL/MIS-14-34029

West Coast Electric Highway Corridor DC Fast Charger Usage

West Coast Electric Highway

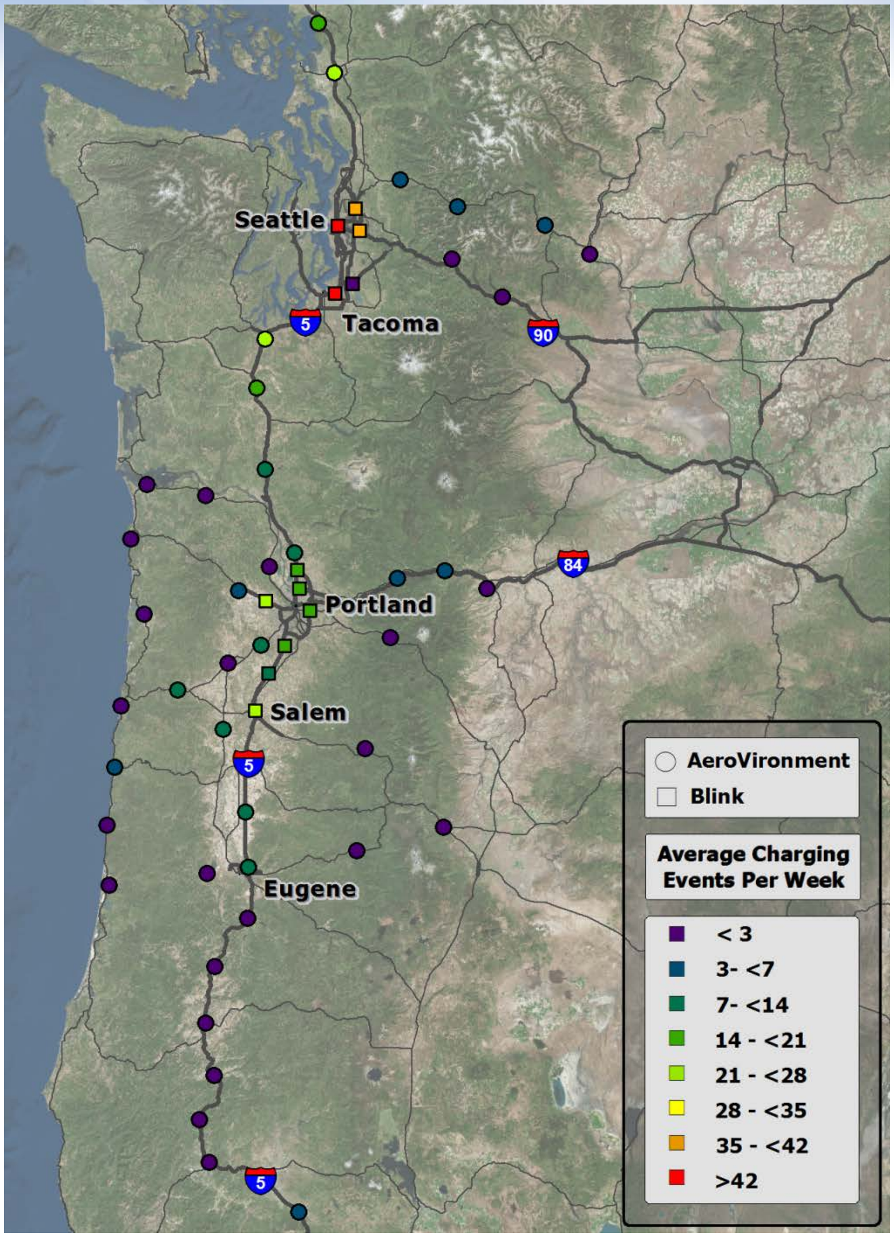
- WCEH was designed to support long distance EV travel in WA, OR, and CA
- Analysis included 45 AeroVironment and 12 Blink DCFC located in Oregon and Washington
- Using EV Project data, we can look at Leaf charging at these fast chargers
  - 1,589 EV Project Leafs in Oregon and Washington
  - 319 used at least one of the 57 DCFC in the study
- Driving was analyzed based on “outings” – all trips taken between leaving home and returning home



DCFC Usage Frequency

9/1/2012 to 1/1/2014

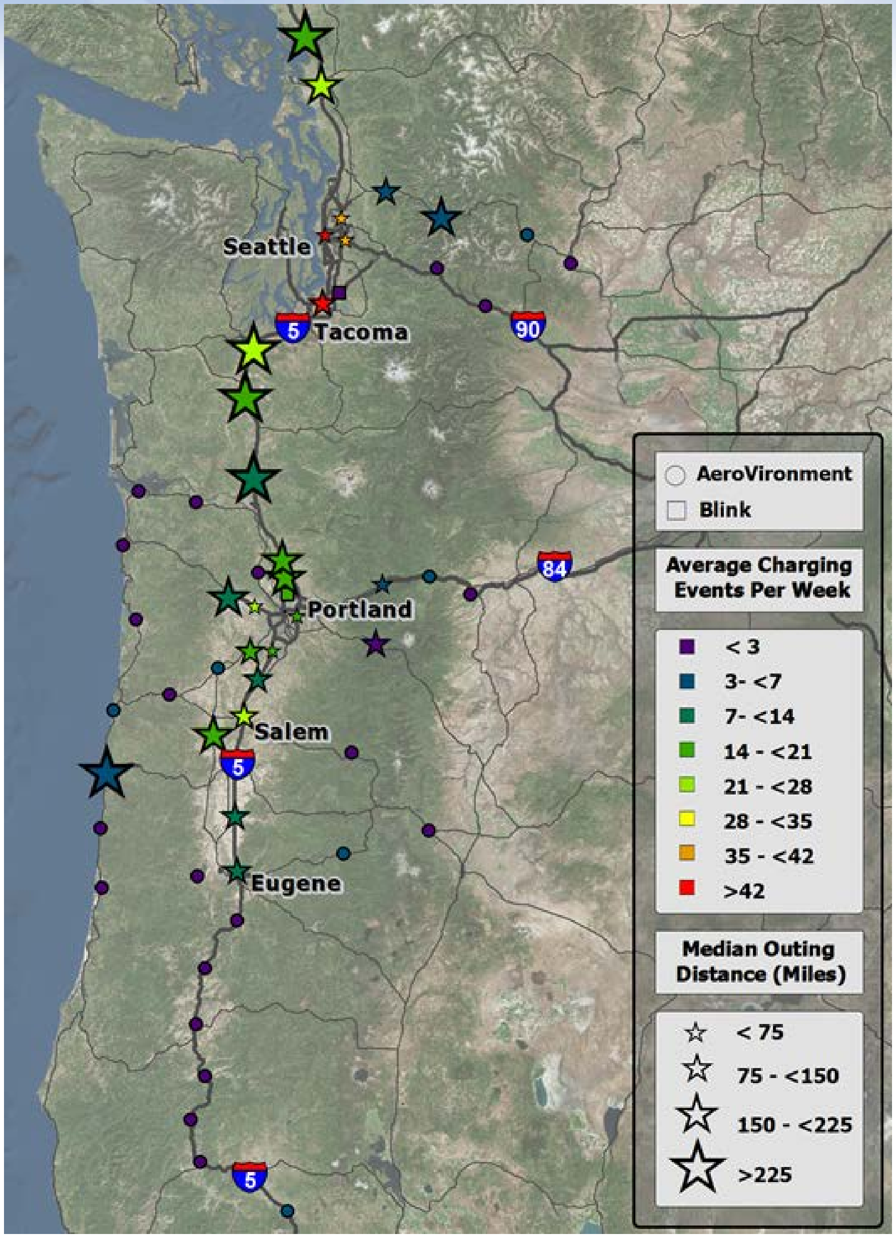
- Most highly used DCFC were in large cities and along interstate between them (Seattle, Portland)
  - Used 2 to 5 times per day, or more
- Usage tends to decrease as DCFC get farther from I-5
  - Also drops off south of Eugene
- DCFCs along the coast and east of I-5 were used a few times per week
  - This low frequency does not provide high value to DCFC owner
  - But each charge may be highly valued by the Leaf owner!



Median Outing Distance

9/1/2012 to 1/1/2014

- DCFC in cities were used in much shorter outings (usually less than full charge range of Leaf)
- As distance from DCFC to cities increases, outing distance increases
- Many DCFC along I-5 were used 2 to 4 times per day for outings over 150 miles
  - Some >225 miles
  - Regularly being used for outings that require 2,3, or more full charges to complete



Full report is being reviewed for publication
INL/EXT-15-34337

Steady State Power Quality Test Results – 2012 Chevrolet Volt

Advanced Vehicle Testing Activity

Idaho National Laboratory

Steady State Vehicle Charging Fact Sheet: 2012 Chevrolet Volt

Description

The steady state charging behavior of a 2012 Chevrolet Volt was tested at many different charge rates. Testing measured the efficiency and power quality of the vehicle charging. Vehicle charging is considered to be in steady state when the RMS current magnitude is not changing and the voltage source is close to nominal. Testing was done for both 120 volt Level 1 charging and 208 volt Level 2 charging.

Key Insights from Testing

- Chevrolet Volt charging is most efficient and has the best power quality when charged at the maximum charge rate.
- When reducing the charging of a group of Chevrolet Volts, it is better to charge a subset of the vehicles at the maximum charge rate than to continue to charge all of the vehicles at a reduced charge rate.[1]

Vehicle Specifications

Vehicle Type: Extended range electric vehicle
Class: Compact
Battery: Lithium-ion
Battery Capacity: 16 kWh
Usable Battery Capacity: 12 kWh
Charge Port: J1772 compatible
DC Fast Charge: No

Electrical Measurement Points[2]

- AC Input: EVSE Output
- DC Output: On Board Charge Module Output

Source Characteristics[3]

Nominal Frequency	60 Hz
Nominal Voltages	120 V / 208 V
Max Deviation from Nominal Frequency	0.08%
Max Deviation from Nominal Voltage Magnitude	2.48%
Max Voltage Total Harmonic Distortion (THD)[4]	2.26%

Load Characteristics

Level 1 - 120 V Test

	Min Charge Rate	Max Charge Rate
Charge Rate	0.65 kW	1.38 kW
Current[5]	5.48 A	11.79 A
Efficiency[6]	84.2%	86.6%
Power Factor[7]	0.990	0.997
Current THD[4]	14.41%	7.88%

Level 2 - 208 V Test

	Min Charge Rate	Max Charge Rate
Charge Rate	1.15 kW	3.14 kW
Current[5]	5.59 A	15.12 A
Efficiency[6]	82.2%	88.5%
Power Factor[7]	0.987	0.998
Current THD[4]	13.73%	6.04%

1. See Example A on page 3
2. The DC output electrical measurement point was only used to calculate efficiency
3. The voltage source was close to nominal during the testing
4. See definition of total harmonic distortion on page 3
5. Current magnitudes are given in RMS values
6. See definition of efficiency on page 3
7. See definition of power factor on page 3

For more information, visit avt.inl.gov
INL/EXT-15-34055
Page 1

To access the full report on the INL website, go to:

avt.inl.gov/pdf/EREV/SteadyStateVehicleChargingFactSheet2012Volt.pdf

INL/EXT-15-34055

Description and Key Insights

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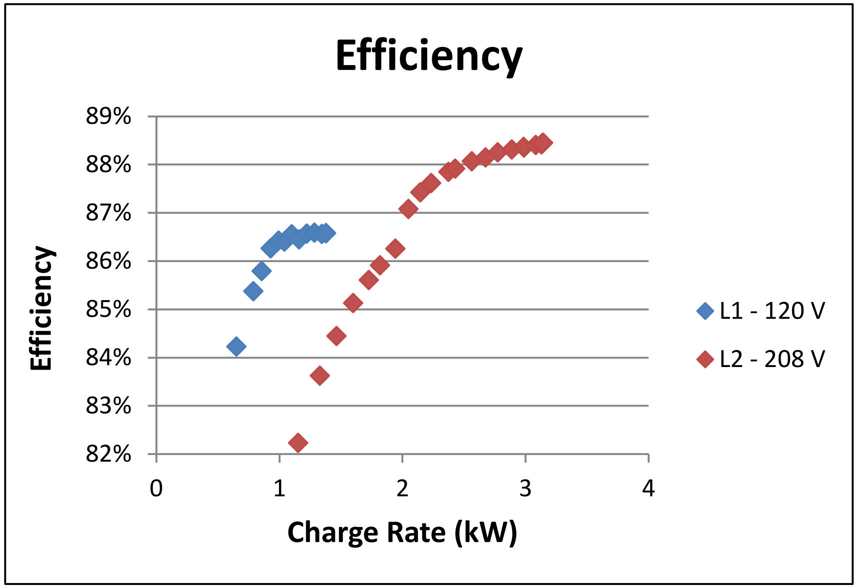
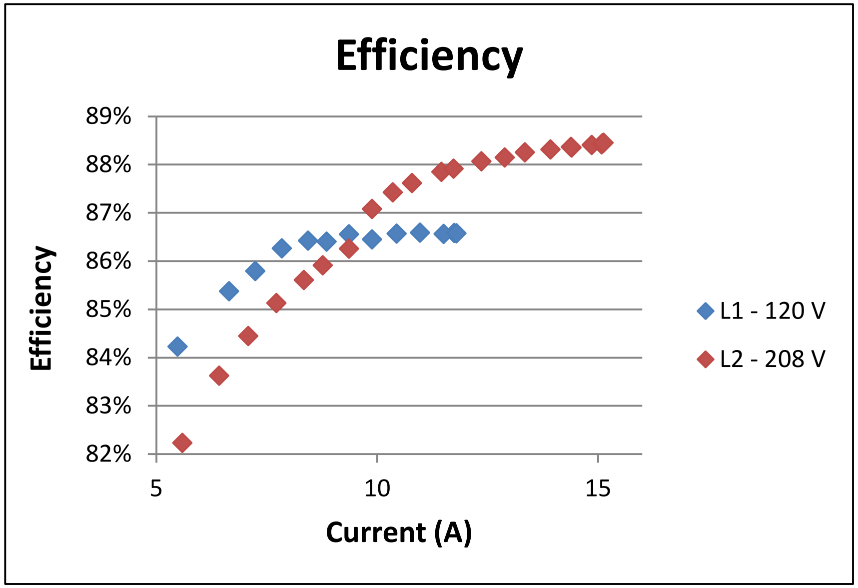
Efficiency

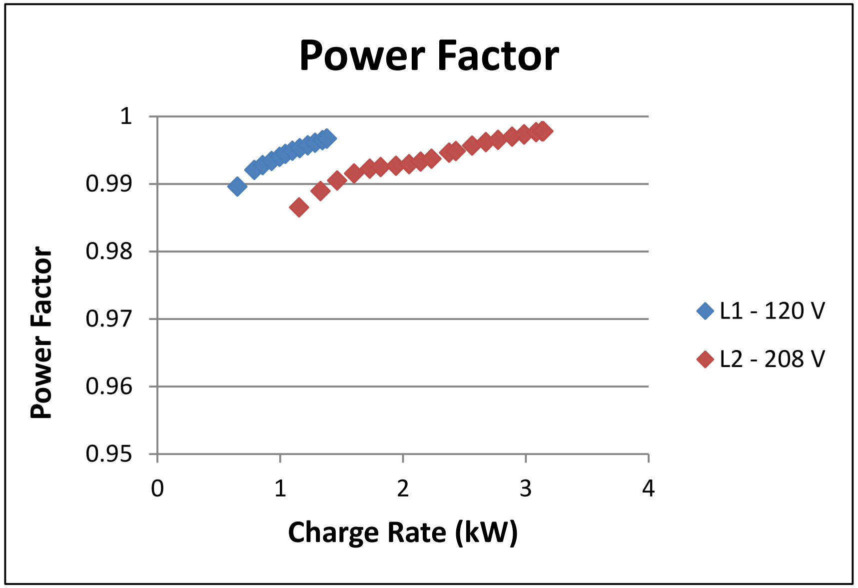


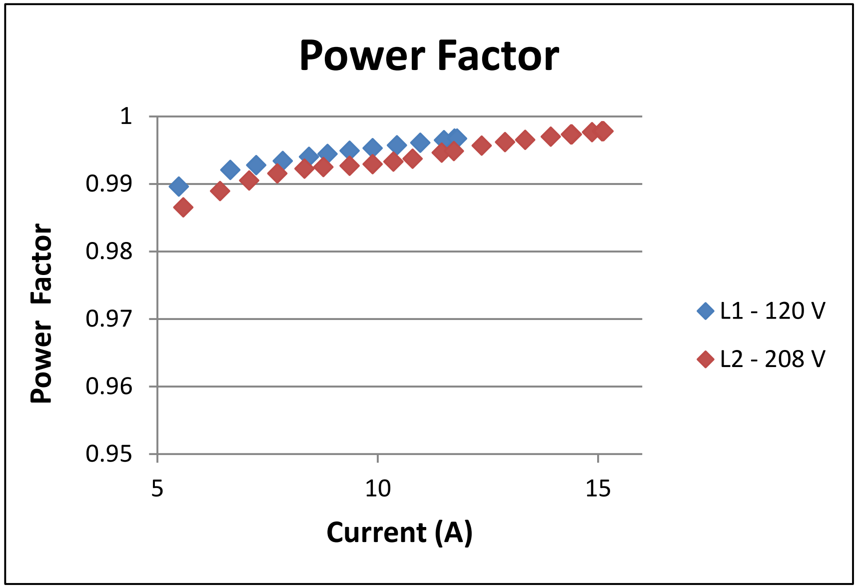
Efficiency
89%
88%
87%
86%
85%
84%
83%
82%
Efficiency
0
1
2
3
4
Charge Rate (kW)
L1 - 120 V
L2 - 208 V



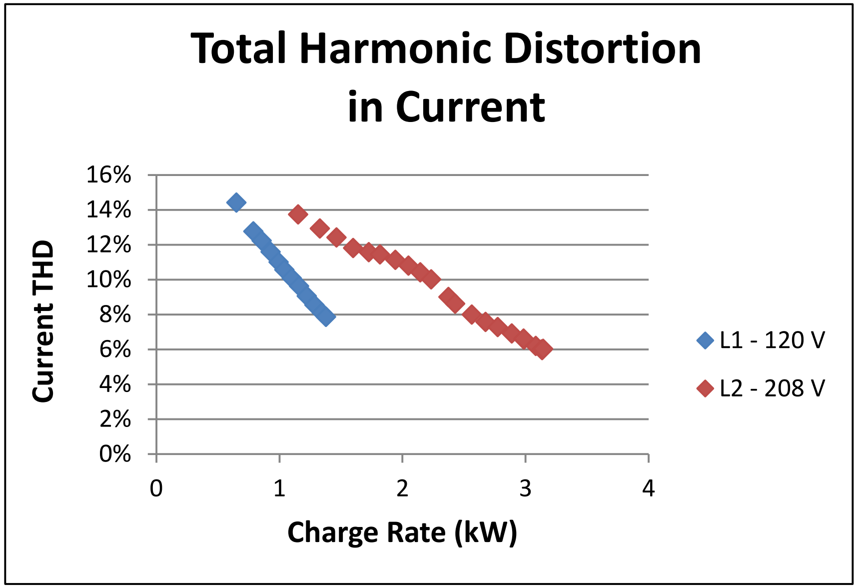
Efficiency
89%
88%
87%
86%
85%
84%
83%
82%
Efficiency
5
10
15
Current (A)
L1 - 120 V
L2 - 208 V

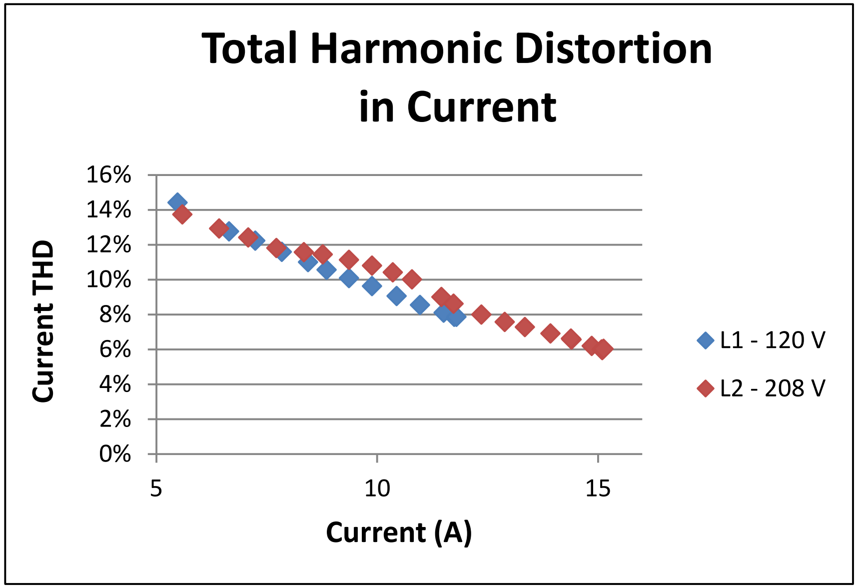
Power Factor



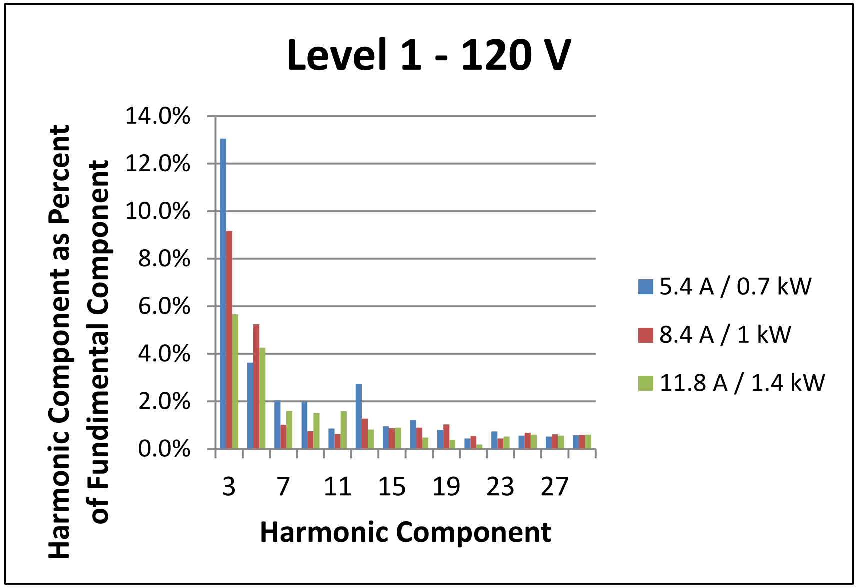


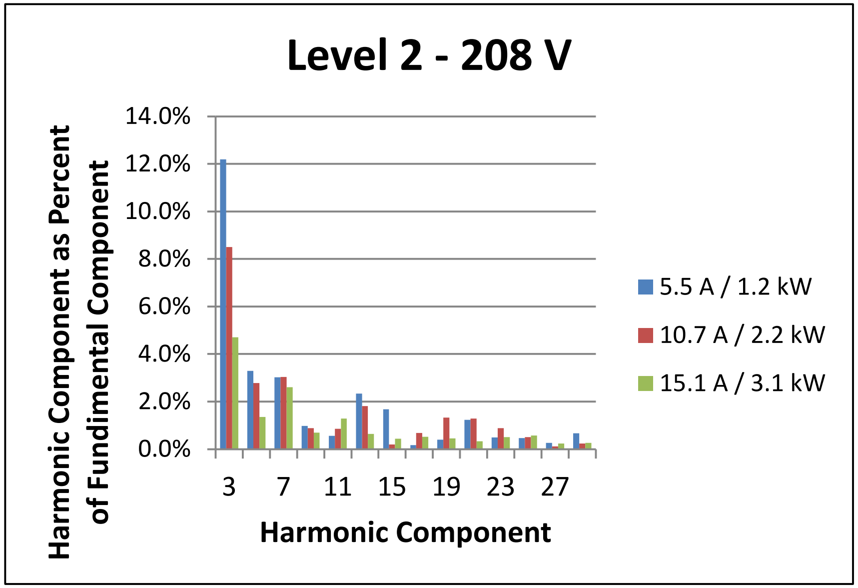
Total Harmonic Distortion in Current





Harmonic Component





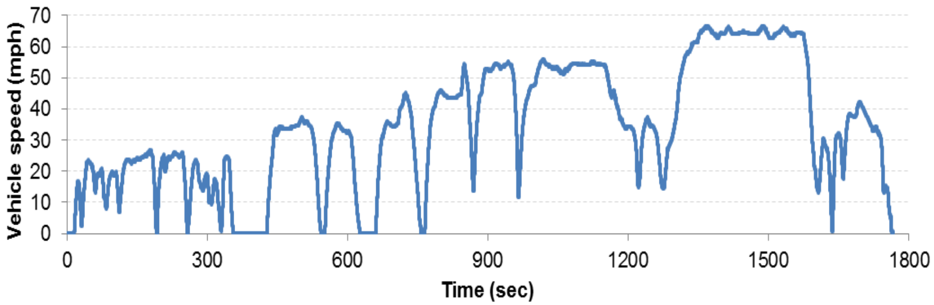
Cold Weather On-road Testing of a 2012 Chevrolet Volt

On-road testing of a 2012 Chevrolet Volt

- Testing was performed during the winter and spring months to determine the impact of cold temperature on driving and charging efficiency
- A single test vehicle was parked and charged overnight in an unsheltered parking stall and driven by a single driver in the morning along a specified route
- Both the vehicle and the charging equipment were instrumented to record energy consumption and other usage parameters during driving and charging

Test Route

- The 16.9 mile route included a mix of rural, city, and highway roads in the Idaho Falls, Idaho area



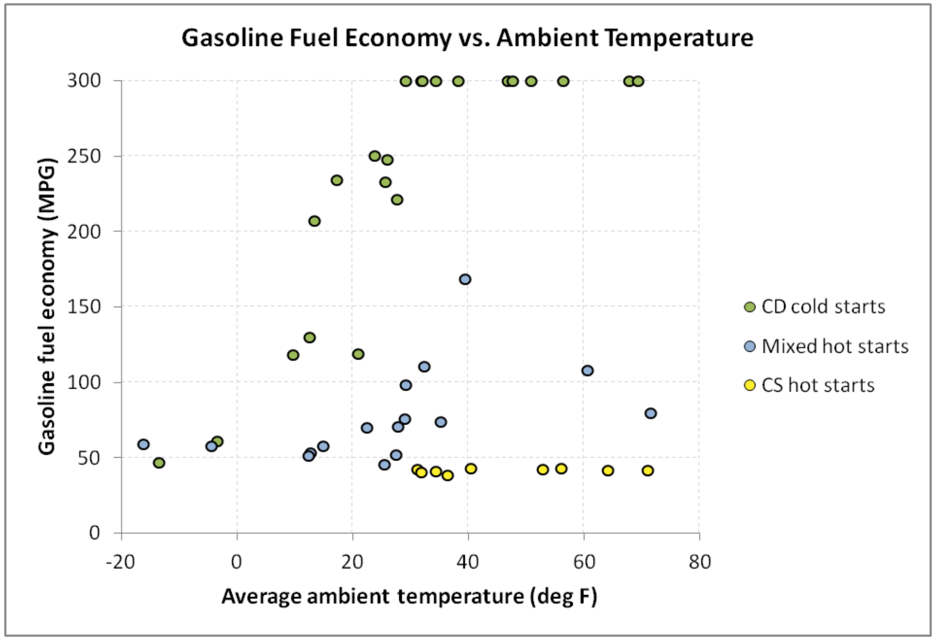
A typical profile of vehicle speed versus time for the Idaho Falls cold weather test route

Performance Metrics

- Ambient temperatures ranged from -17°F to 70°F during testing
- The following metrics were tracked:
  - Gasoline fuel economy (mpg)
  - Electrical energy consumption (Wh/mi)
  - Electric-only (EV) mode range (mi)
  - Charge depleting (CD) mode range (mi)
- All varied significantly as ambient temperature varied

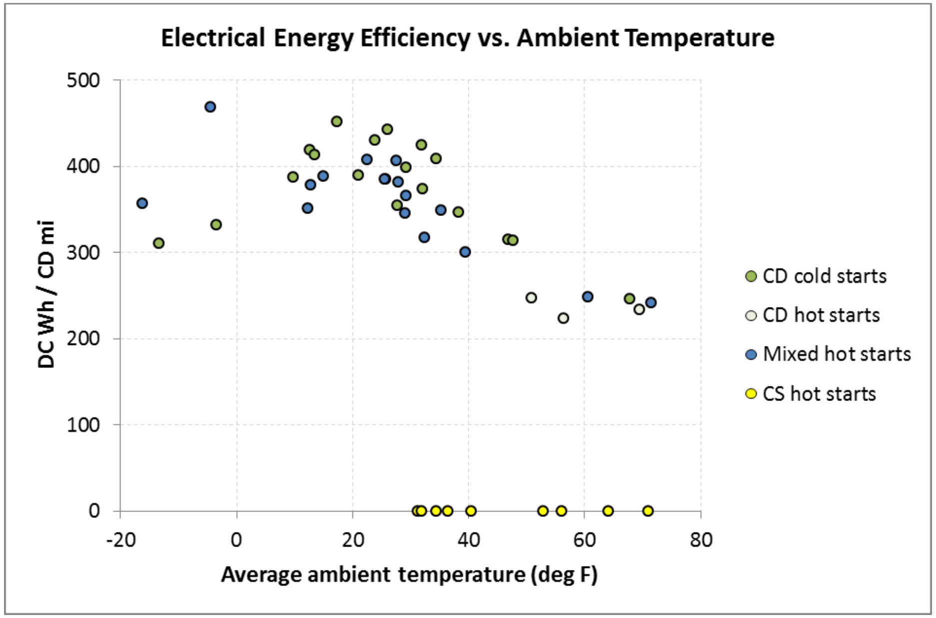
Vehicle Driving Efficiency – Gasoline Fuel Economy

- As an all-electric capable vehicle, the Volt was able to complete the test route without consuming any gasoline, until the ambient temperature fell to 27°F
- At 27°F, the vehicle's control system commands the engine to cycle on
- At even lower temperatures, the engine cycled on more frequently and fuel economy dropped further
- At -15°F, test fuel economy was 47 mpg, which approached charge sustaining operation fuel economy



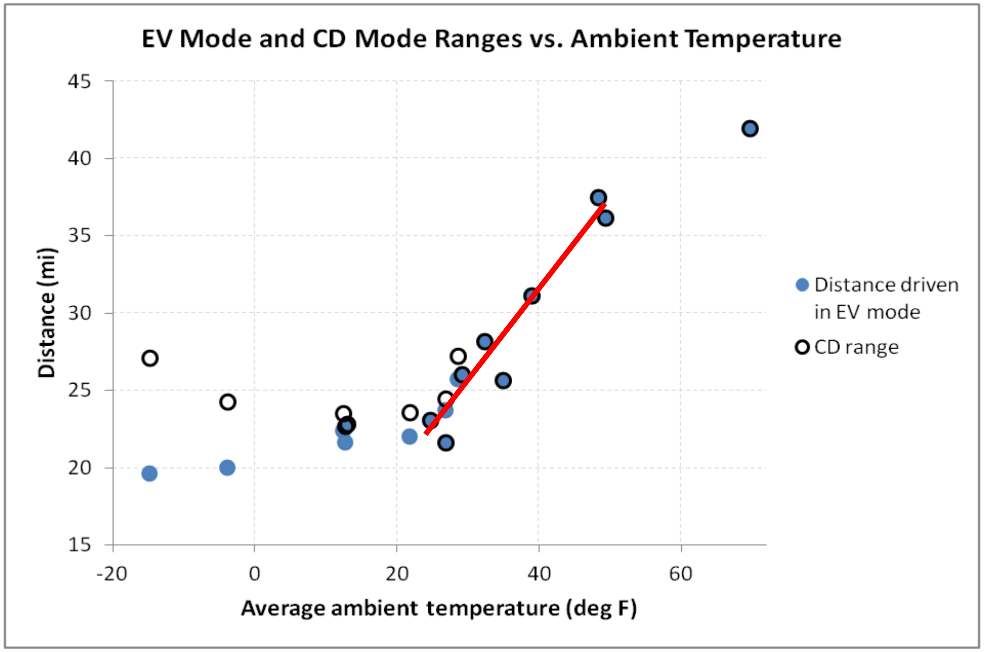
Vehicle Driving Efficiency – Electrical Energy Consumption

- Electrical energy efficiency across all CD tests with cold starts ranged from 246 DC Wh/mi to 452 DC Wh/mi
- This 84% increase in consumption can be attributed to the effects of cold temperature and climate control load
- During the coldest CD test, electrical energy efficiency during this test was 311 DC Wh/mi
- Cold start test consumed more energy than hot starts



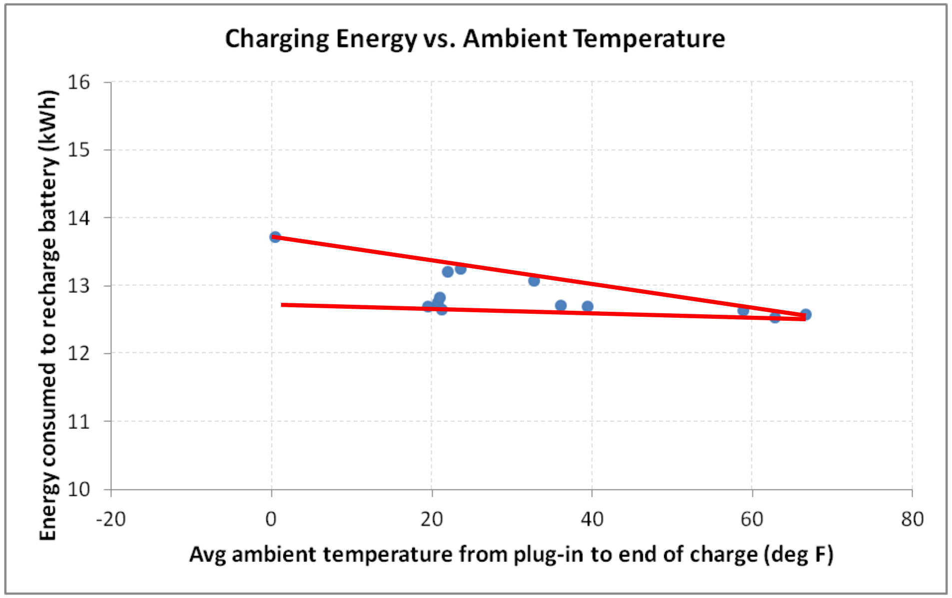
EV and CD Mode Range

- The Volt's full-charge EV range dropped from 42.0 miles at 70°F to 19.7 miles at -15°F, a reduction of 53%
- EV range fell off fairly linearly in tests averaging 50 to 25°F at a rate of 0.6 miles per deg F
- CD range diverged from EV range in tests when temperatures were 27°F or less, because engine operation due to cold temperature also slowed the rate of battery depletion



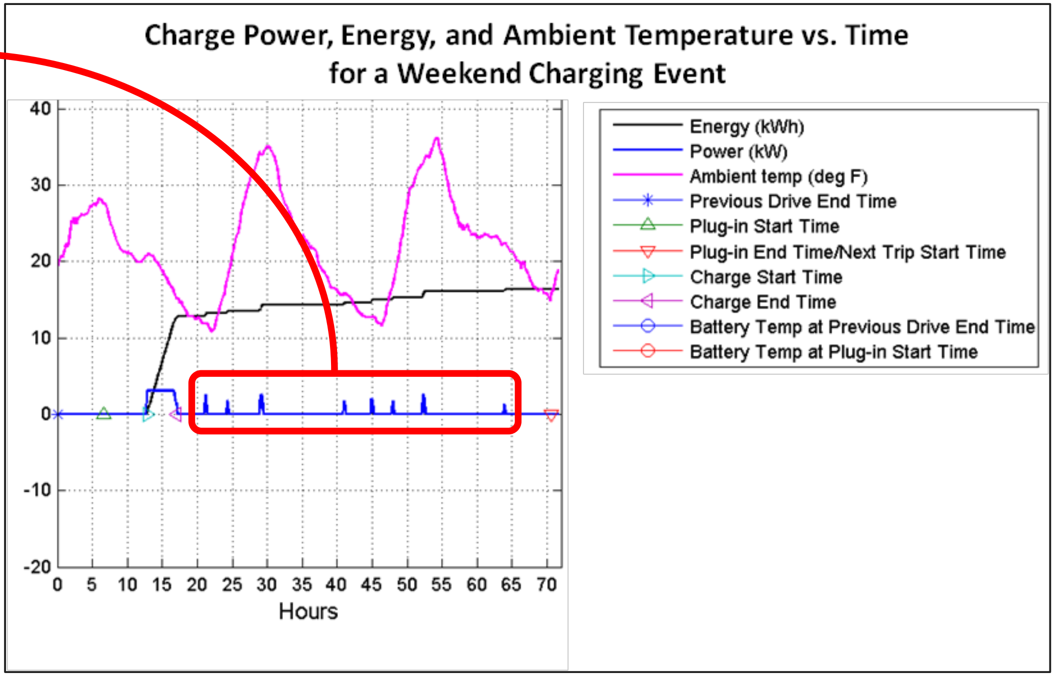
Vehicle Charging Efficiency

- Energy consumption during overnight charging ranged from 12.53 to 13.73 AC kWh (10% increase)
- Energy consumption increased with decreasing temperature, but not at a consistent rate
- Additional instrumentation is required to determine the cause of this variation



Vehicle Charging Efficiency (cont.)

- The Volt draws power after charging to heat the battery
- This post-charge power draw resulted in additional energy consumption of 3.56 AC kWh for the charging event shown
- Naturally, the energy consumed due to post-charge power draw is a function of how long the vehicle remains plugged in
- The short power spikes peaked between 1.8 to 2.6 kW and lasted for 10 to 25 minutes



Time history data for a charging event when the vehicle was left plugged-in over the weekend.

To access the full report on the INL website, go to: avt.inl.gov/pdf/phev/2012VoltColdWeatherTestReport.pdf