Battery Energy Availability and Consumption during Vehicle Charging across Ambient Temperatures and Battery Temperature

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Project ID # VSS110
Overview

- **Timeline**
  - 2013 Recharge Testing/Analysis Tasks
    - Chevrolet Volt Testing – Complete
    - Nissan Leaf Testing - Complete
    - Toyota Prius PHV Testing - Complete
    - Ford Focus BEV Testing – On-going
      - In-depth benchmarking 2014 AOP task
    - Final reporting – On-going

- **DOE VSSST barriers addressed**
  - Constant advances in technology
    - **F**: Constant advances in technology
    - **D**: Lack of standardized test protocols
    - **E**: Computational models, design and simulation methodologies (Data availability)

- **Budget**
  - FY 2013 $200k

- **Partners**
  - DOE and other National Laboratories
  - Vehicle OEMs, and Suppliers
  - Standards development working groups
Previous vehicle testing has shown battery cooling system operation during recharge can have an appreciable impact:

- AC wall power remains the same during charge, but battery recharge in-flow can be reduced during cooling/heating
- Efficiency and charge time will vary depending on battery state

Complex battery heating/cooling systems more prevalent:

- Many PHEVs and BEVs have separate battery thermal management

Stand-by loads for cooling/heating may be significant:

- Limited information for measuring and evaluating these impacts

In a V2G scenario, available power may be reduced:

- Unanticipated reduction in loading capability/functionality
### Approach/Strategy: PHEV/BEV Evaluation of Vehicles

A range of PHEV and EV test vehicles were evaluated...

- Available PHEV/BEVs for testing
- Range of operating styles
- Range of charger capabilities
- Range of battery thermal management capabilities

List of technologies assessed is by no means exhaustive, but provides some insights across a fairly wide range of possibilities

<table>
<thead>
<tr>
<th>Vehicle</th>
<th>Battery Power</th>
<th>Charging Power</th>
<th>Battery Cooling</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ford Focus (BEV)</strong></td>
<td>110 kW</td>
<td>~6.6 kW</td>
<td>Liquid cooled/heated</td>
</tr>
<tr>
<td><strong>Chevrolet Volt (PHEV)</strong></td>
<td>111 kW</td>
<td>~3.3 kW</td>
<td>Liquid cooled/heated</td>
</tr>
<tr>
<td><strong>Nissan Leaf (BEV)</strong></td>
<td>90 kW</td>
<td>~3.3 kW</td>
<td>Minimal battery cooling</td>
</tr>
<tr>
<td><strong>Toyota Prius (PHEV)</strong></td>
<td>37 kW</td>
<td>~2.6 kW</td>
<td>Air cooled battery pack</td>
</tr>
</tbody>
</table>
**Approach/Strategy: Instrumentation and Testing**

Assessing charging loads across a range of hot/cold battery and ambient conditions requires careful test sequencing and instrumentation.

**Testing considerations include:**

- Ambient recharge temperature
  - Thermal management during long charges
- Vehicle soak time and temperature
  - Large battery thermal capacity
  - Observed cooling over multiple cold days
- Battery usage prior to charging
  - How much battery cooling prior to charging
- Vehicle HVAC settings
  - Hot/Cold runs done with/without HVAC to assess battery specific demands before charge

**Highlighted Instrumentation:**

- Battery current loop – Required to measure actual battery current
- OCR Battery Measurement – PEV batteries difficult to directly instrument
- HVAC Instrumentation – Loads during charging
  (can be tricky with complex thermal/HVAC systems)
Accomplishments: Highlighted Battery Cooling Results

- Chevrolet Volt shows two cooling operations during recharge under hot conditions...
  - Cooling during battery charging (~500W DC load)
  - Cooling during stand-by (~1000W AC Load)

- Other observations
  - Cooling system activates at roughly 31°C
  - Only hot soaked battery showed cooling during charge
  - Cooling during driving much more aggressive...

Chevrolet Volt: Hot ambient steady-state operation

Chevrolet Volt: Hot ambient recharge following hot charge depletion
Accomplishments: Highlighted Battery Cooling Results

- Stand-by cooling only observed during hot ambient charging
- Initial thermal state impacts battery cooling behavior
  - Cooling system often only activates once CS operation achieved for normal operation
  - Hot soaked battery requires cooling before CS despite less aggressive cycle

Chevrolet Volt: Aggressive (US06) operation at normal conditions

Chevrolet Volt: Hwy operation under hot conditions
Accomplishments: Highlighted Battery Cooling Results

- Other vehicles show a mix of behaviors regarding battery cooling during recharge
  - Preliminary Focus BEV testing shows some cooling during charge at normal ambient
    - Much smaller loads, likely associated with fan/pump operation (highlighted in figure below)
    - Actuation varies by usage...more aggressive cycles see operation sooner
  - Prius PHEV shows no de-rating due to increased battery temperatures from hot soak
    - PHEVs in general are less sensitive due to engine capability to offset power requirements (depends on operation style)

Ford Focus BEV: Battery Recharge Current

Prius PHEV: Battery power limits vs. SOC for hot and normal soaked battery
Accomplishments: Highlighted Battery Heating Analysis

- During cold ambient recharge (-7°C) Volt shows stand-by heating loads (~2.5 kW wall power)
  - Behavior differs depending on soak time...1st cold recharge shows no stand-by loads
  - Despite conditioning, vehicle still initially operates with engine on even with cabin HVAC system in-active
    > EVs may require more thermal stabilization depending on soak time due to lack of engine power

Chevrolet Volt: Cold Ambient Charge
Accomplishments: Cold Battery Operational Analysis

Other vehicles show reduced battery power during lower temperature testing...

- Suggests possibility for increased usage of thermal management systems
- Prius PHEV shows significantly reduced charge power and slightly reduced discharge power
- Nissan Leaf shows reduced regen. power following cold soak and recharge

Nissan Leaf UDDS Battery Usage for Normal and Cold Ambient Operation
Collaborations and Coordination with Other Institutions

AVTA (Advanced Vehicle Testing activities)
- In-depth vehicle and component evaluation

Battery Energy Availability and Consumption

USDRIVE, tech teams and OEMs
- Shared data and analysis

J1711 HEV & PHEV test procedures
J1634 EV test procedures

DOE technology evaluation
- DOE requests
- National Lab requests
- Overall energy analysis

SAE International
Summary

Thermal management loads during recharge were assessed for recent battery electric and plug-in hybrid vehicles across a range of ambient and battery temperatures, findings include:

- Initial thermal state impacts battery cooling behavior
  - For PHEVs, CS operation is often reached before cooling is required when starting from normal (~25C) ambient temperature
- Chevrolet Volt shows two cooling operations when plugged-in under hot conditions
  - Cooling during battery charging (~500W DC load) and cooling during stand-by (~1000W AC)
- Stand-by cooling only observed during hot ambient charging
  - While plugged-in, Volt shows intermittent stand-by heating
    - Occasional ~2.5 kW AC wall-load for heating while plugged-in and not charging
- Other vehicles show reduced battery power during lower temperature testing...
  - Suggests possibility for more prevalent thermal management during recharge in the future