Impact of Fast Charging on Life of EV Batteries

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Introduction and Overview

I. Objectives:
   1. Modify travel data collected from conventional gasoline vehicles to include stops at fast charge stations as necessary during simulation of battery electric vehicles
   2. Study impact of fast charging on vehicle utility, battery thermal management, and simulated battery degradation rate

II. BLAST tour planning
   1. Nominal method
   2. Rerouting for stops at fast charge stations

III. Fast charge impact analysis
   1. Public EVSE availability
   2. Example simulation of fast charge event
   3. Sensitivities to fast charge availability, climate, BTMS, and driving profile
Techno-Economic Analysis Tool: BLAST-V

• Battery Lifetime Analysis and Simulation Tool for Vehicles
• Objective: Perform accurate techno-economic assessments of HEV, PHEV, and BEV technologies and operational strategies to optimize consumer cost-benefit ratios, petroleum use reductions, and emissions savings

1. Real-world driver aggression profiles
   - 317 real-world, year-long trip histories

2. Range estimation algorithms inform travel decisions

3. Infrastructure Model

4. Advanced vehicle simulation includes full drivetrain consideration, cabin thermal model, HVAC system, and more.
   - 100 city-specific climate histories

5. Battery electrical and thermal models

6. First-Life Accounting: Economics, mileage, fuel use, greenhouse gases, etc.

7. Automotive Use, Second Use, Recycle Decision

Other Accounting Inputs:
- Cost of gasoline
- Cost of electricity
- Cost of vehicle components
  - Cost of unachievable travel
  - Taxes
  - Purchase incentives
  - Loan parameters
  - Driver discount rate
  - Etc.
Assumptions

I. 180 12-month driving histories from the Seattle area
   1. Collected in conventional vehicles w/o FC stops

II. 75 mile BEV (22kWh pack)

III. DC Fast charge stations provide 50kW

IV. Level 2 home charging (6.5kW), no Work Charging
   1. Work charging was investigated using BLAST in recent journal article
      “The impact of range anxiety and home, workplace, and public charging
      infrastructure on simulated battery electric vehicle lifetime utility”
      *Journal of Power Sources, July 2014.*

V. NCA/graphite life model

VI. Pack thermal model considers connections to ambient and cabin

VII. Cabin HVAC loads dynamically calculated and impact vehicle range
Tour Planning in BLAST - 1

Example Tour 1

<table>
<thead>
<tr>
<th>Depart / Arrive</th>
<th>Miles</th>
<th>Minutes</th>
<th>Estimated SOC</th>
</tr>
</thead>
<tbody>
<tr>
<td>8:31am / 9:07am</td>
<td>21.2</td>
<td>36.3</td>
<td>100% → 81%</td>
</tr>
<tr>
<td>4:33pm / 4:48pm</td>
<td>9.9</td>
<td>15.6</td>
<td>81% → 73%</td>
</tr>
<tr>
<td>5:39pm / 6:10pm</td>
<td>13.7</td>
<td>30.9</td>
<td>73% → 61%</td>
</tr>
</tbody>
</table>

BLAST estimates SOC through tour using reduced order battery model.

If minimum estimated SOC is above driver’s range tolerance, BLAST proceeds with simulating the tour, otherwise tour is evaluated as single parked event.
Tour Planning in BLAST - 2

Example Tour 2

<table>
<thead>
<tr>
<th>Depart / Arrive</th>
<th>Miles</th>
<th>Minutes</th>
<th>Estimated SOC</th>
</tr>
</thead>
<tbody>
<tr>
<td>8:14am / 8:40am</td>
<td>20.0</td>
<td>26.3</td>
<td>100% → 79%</td>
</tr>
<tr>
<td>12:34pm / 1:11pm</td>
<td>35.0</td>
<td>37.0</td>
<td>79% → 42%</td>
</tr>
<tr>
<td>3:55pm / 4:36pm</td>
<td>37.3</td>
<td>41.2</td>
<td>42% → 3%</td>
</tr>
<tr>
<td>5:49pm / 6:07pm</td>
<td>13.6</td>
<td>19.0</td>
<td>3% → 0%</td>
</tr>
</tbody>
</table>

If minimum estimated SOC drops below range tolerance, BLAST attempts to reroute select trips to include stops at fast charge stations.
BLAST considers two data sources when rerouting tours

1. Alternate path of travel combinations using O/D pairs from original travel data and Google Maps Directions API
2. User-defined EVSE networks

Using said input data, BLAST reschedules the original tour while attempting to:

- Keep minimum estimated SOC above driver tolerance
- Minimize number of stops and time spent at FC stations

*Constraint is applied that all trip start times be preserved from original travel data*
Tour Planning in BLAST - 4

- All rerouted trips start on time (per original data)
- BLAST records statistics on incremental driving time and distance resulting from rerouting and FC stops
- Algorithm can enable very long tours that require several stops at fast charge stations. While such tours are deemed feasible during tour planning, BLAST will additionally evaluate the thermal and life impacts of such an aggressive cycling profile

<table>
<thead>
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<th>Miles</th>
<th>Minutes</th>
<th>Estimated SOC</th>
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</thead>
<tbody>
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<td>35.0</td>
<td>37.0</td>
<td>79% → 42%</td>
</tr>
<tr>
<td>3:55pm / 4:03pm</td>
<td>7.8</td>
<td>8.3</td>
<td>42% → 34%</td>
</tr>
<tr>
<td>4:20pm / 4:53pm</td>
<td>30.0</td>
<td>32.9</td>
<td>95% → 62%</td>
</tr>
<tr>
<td>5:49pm / 6:07pm</td>
<td>13.6</td>
<td>19.0</td>
<td>62% → 49%</td>
</tr>
</tbody>
</table>

Example Tour 2: Rerouted Tour w/ stop at FC station

17 minute FC
Baseline EVSE Scenario

- For analysis of fast charging (FC) impact on batteries, it was necessary to select a baseline public infrastructure scenario.
- The Pacific Northwest has fairly good geographic coverage of existing FC stations already in the ground:
  - 34 existing FC stations in Washington State.

Existing DCFC Stations (source: NREL Alternative Fuels Data Center, Jan 2014)
Simulation Sweep

I. Perform 10 years of battery simulations for 180 driving profiles given…

1. EVSE:
   1) L2 home charging
   2) L2 home charging + present day FC station availability

2. Climate:
   1) Seattle (coincident with travel data)
   2) Phoenix (worst case thermal management)

3. Battery Thermal Management System:
   1) Passive cooling
   2) High-power liquid cooling (active driving)
   3) High-power liquid cooling (active driving + charging)
I. Average driver utilized FC 10 times in first year of life
   1. Extreme case driver utilized FC at an average rate of 8 times a month

II. FC utilization correlates well with incremental VMT

III. Some drivers complete 100% of travel w/o need for FC
FC Utilization & Validation

I. BLAST runs reveal average FC connection times of 10-22 minutes
   1. Dependent on arrival SOC

II. EV Project data indicated average FC connection times of 14-24 minutes

EV Project Data

- This presentation was given for the Navigant Research Webinar on Fast DC Charging for Electric Vehicles
  - [http://www.navigantresearch.com/webinar/fast-dc-charging-for-electric-vehicles](http://www.navigantresearch.com/webinar/fast-dc-charging-for-electric-vehicles)
  - April 9, 2013
INL DC Fast Charging Impact Study on 2012 Leafs

- Level 2 Leafs averaged 75.2% SOC @ 50k miles
- DCFC Leafs averaged 72.6% SOC @ 50k miles
- 2.6% capacity difference @ 50k miles, probably not a significant difference
FC Utilization & Validation

I. BLAST aggregates charge energy by location
II. Group all FC locations together and average driver receives 7.6% of energy from fast charging
   1. Max: 41.5%
   2. Min 0.0%
III. EV Project reports fast charges accounting for 1-21% of all charge events for Nissan Leaf’s under study that frequently used fast chargers
   1. Where a cost for fast charging was present, 8% of charging energy came from fast charging for Nissan Leaf’s under study
Seattle Results: Incremental Utility

I. FC availability improves utility for most drivers
   1. Annual VMT increases by 800 miles on average
   2. Annual tours not taken decreases by 8 on average
Other Effects

Due to the low frequency of fast charger usage, average battery temperature and capacity loss are negligibly affected.
Seattle Results: Battery Max Temp

I. Impact of FC was most observable in maximum pack temperatures from passively cooled packs

1. Back-to-back sequencing of drive-FC-drive produces significant heat generation resulting in dangerous thermal conditions

II. Simulated packs with high capacity cooling systems were able to mitigate heat generation on FC tours and maintain safe thermal conditions
Example Fast Charging + Passive Cooling (1 yr)
Example Fast Charging + Passive Cooling (14 hrs)

Temperature, °C

Cell SOC

Time, hours

75° C
Variation Within the Pack

I. Instantaneous thermal gradients are affected by fast charging

II. Variation of degradation within a pack is affected less so, due to infrequency of fast charge events

Distribution across cells in one pack
I. Utilization of public charging infrastructure is heavily dependent on user-specific travel behavior

II. Fast charger availability can positively affect the utility of BEVs, even given infrequent use

III. Estimated utilization rates do not appear frequent enough to significantly impact battery life

IV. Battery thermal management systems are critical in mitigating dangerous thermal conditions on long distance tours with multiple fast charge events
Acknowledgments

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