Predictive Battery Management for Commercial HEVs

ARPA-E AMPED  DE-AR0000279
Predictive Battery Management for Commercial Hybrid Electric Vehicles

Overview

**Partners:** Eaton, National Renewable Energy Lab

**Funding and Duration:** $2.8M, 36 months
- ARPA-E: $2M, Eaton Cost Share: $0.8M

Technology

- Battery life prognostics based on electrochemical dynamics, capable of fast and accurate estimation of battery health and residual life
- Predictive Powertrain Controls with Intelligent Electric Power Management System, capable of vehicle duty cycle prediction and real-time co-optimization of fuel economy and battery life

Advantage and Differentiation

- Combines model-based battery prognostics with vehicle duty cycle prediction
- Integrates powertrain control with battery management
- Enables dynamic battery utilization to achieve required system performance from a significantly downsized battery pack with minimum impact on battery life:
  1. Lower cost and higher ROI for HEVs
  2. Accurate residual battery life estimation for improved estimation of secondary market

Performance Targets

<table>
<thead>
<tr>
<th>Metric</th>
<th>State of the Art</th>
<th>Proposed</th>
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<tbody>
<tr>
<td>Battery pack cost, weight and capacity</td>
<td>Oversized by factor of 4</td>
<td>Battery downsizing by 50% while maintaining life and performance</td>
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<tr>
<td>Battery residual life prediction</td>
<td>Prediction uncertainty of nearly 30%</td>
<td>Electrochemical model capable of error of less than 10%</td>
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Opportunity and Challenges

1. Current HEVs design and control
   - Battery oversized due to “worse case” assumptions on environment conditions and battery usage
   - Powertrain controls forced to underutilize battery pack due to unknown battery aging and BMS limitations

2. Simply downsizing battery only will result in drop in FE performance & battery life

3. Existing study by Eaton also shows FE performance improvement even with downsized battery in one use case but with reduced battery life.

4. Proposed solution maintains baseline battery life while maintaining or improving FE performance with downsized battery.

Risks to be retired through the project

- Degrees of freedom available for predictive optimal controls (charge rate, depth of discharge) may not be able to sufficiently overcome the diminished battery life loss once the battery is downsized
- In-lab, cell-level battery prognostics performance from NREL might not be applicable to real-world duty cycles and battery packs
Validation Plan

- Pack-level, accelerated testing with real-world duty cycles
- A and B test (with and w/o predictive management) for evaluation

AMPED HIL Test System

- Data-driven battery life modeling and validation via accelerated testing
- Simulated battery load cycle based on real-world vehicle duty cycles and validated vehicle model
- Close-loop controls simulation with real-time battery health/status

Verify battery life and performance upper-bound with reduced battery size through simulation

HIL testing: main battery life and FE with 50% battery size reduction
Year 1 Progress: Battery Modeling

- **Life Modeling**
  - Physics-based mechanisms for correct separation & coupling of calendar- vs cyclic-driven fade
  - Initial model ID using cell aging tests
  - To be refined and validated using pack-level testing with real-world duty cycles and various temperature conditions

- **Thermal modeling**
  - Captures both pack average and worst cell behavior

**AMPED Project Cell Aging Test Campaign**

**Life**
- Aging DOE
- Drive-cycle, Environment

**Electrical**
- Physical mechanisms
- Onboard models capturing life/ performance/ temperature tradeoffs versus vehicle supervisory control decisions

**Thermal**
- Captures both pack average and worst cell behavior

**Pack-level testing for thermal modeling**
**Year 1 Progress: Controls**

**Challenges**
- Slow battery life feedback vs. fast vehicle & fuel consumption dynamics
- Multiple control objectives with different time scale
- Various hard constraints on battery operation

**Solution**
- A battery utilization cost function integrated into a predictive powertrain control strategy which dynamically adjusting the “cost” of battery usage

**Year 1 progress to date**
- Verify PPM’s potential through simulation

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**Simulation results for downsizing using various PPM strategies**

- 0%: Red
- 15%: Blue
- 35%: Green
- 50%: Black

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**Battery Life [y]**

- Trading FE with Life
- Baseline control with 0-50% downsizing

**Fuel [mile/gal]**