Potential Efficiency Improvement by Accessory Load Reduction on Hybrid Transit Buses

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Center for Diesel Research
Acknowledgements

• Jeff Campbell – lead graduate student

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Transit Energy Use and Cost

- 633 M gallons diesel used for US transit in 2010 [1]
- Equivalent cost $2.5B at 2012 retail fuel prices


http://www.bts.gov/publications/national_transportation_statistics/
Energy Use in Buses

• Significant power used for “Hotel Loads”
  – Air conditioning, steering, doors, cooling pumps, etc.
  – Currently inefficient, especially when stationary or moving slowly
  – Unclear how much and when power is actually needed

• This project – Auditing accessory energy use in a parallel hybrid bus
Electrification of Accessories

Published Work

- **Army** [1]
  - 5-20% improvement

- **EMP** [2]
  - 5-10% improvement (CATA, TriMet)

- No work using actual vehicle monitoring


Accessory Efficiency Breakdown

• Parasitic Loading
  – More power to accessory than is required by its function
  – Accessory efficiency

• Accessory “Overdrive”
  – Accessories tied to engine speed
  – Sized for idle condition
  – Power increases with speed

http://www.shopfbparts.com/servlet/Detail?no=430
Experimental Test Plan

Data Acquisition System
• NI Compact FieldPoint

Collection Details
• 10 day period
• Late summer
  – 145.6 hours of run time
  – Half a million timestamps
    • 39% AC on
    • 61% AC off
The Bus

• 40’ Gillig Low-Floor Bus
  – Parallel hybrid meeting 2007 emission standards
  – Purchased by Metro Transit: March 2008

<table>
<thead>
<tr>
<th>Specification</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Curb Weight</td>
<td>29,550 lbs (13,400 kg)</td>
</tr>
<tr>
<td>Length</td>
<td>41.5 ft (12.6 m)</td>
</tr>
<tr>
<td>Width</td>
<td>8.3 ft (2.5 m)</td>
</tr>
<tr>
<td>Height/Height with Battery</td>
<td>9.0 ft/10.5 ft (2.7 m/3.0 m)</td>
</tr>
<tr>
<td>Wheelbase</td>
<td>23.3 ft (7.1 m)</td>
</tr>
<tr>
<td>Engine Type</td>
<td>2007 Cummins ISB</td>
</tr>
<tr>
<td>Rated Torque</td>
<td>620 lbf-ft (841 Nm) @ 1600 RPM</td>
</tr>
<tr>
<td>Rated Power</td>
<td>260 HP (194 kW)</td>
</tr>
<tr>
<td>Hybrid Drive System</td>
<td>Allison EP40</td>
</tr>
<tr>
<td>Passenger Capacity</td>
<td>38 seated, 28 standing</td>
</tr>
</tbody>
</table>
Accessory Drive Systems Monitored

Directly driven systems

Systems powered by hydraulic drive

Power estimated using thermodynamic data + speed or electrical current
Results – Vehicle and Engine Histograms

- **Bus Speed**
  - Median = 8 km/hr
  - Mean = 16 km/hr

- **3 Engine Modes**
  - Slow idle = 39%
  - Fast idle
  - Main hybrid propulsion
Results – Power Data

- Engine Hydraulic Fan Pump Example
  - Histogram and scatter plot
  - Power wasted at higher speeds
  - Average Input Power = 6.2 kW
Results – Average Accessory Loads

AC Off
- Alternator, 2.3 kW
- Air Compressor, 0.6 kW
- Power Steering, 1.8 kW
- Engine Fan, 6.3 kW
Total: 11.0 kW

AC On
- AC Compressor, 6.1 kW
- Engine Fan, 6.3 kW
- Power Steering, 1.8 kW
- Alternator (AC fans), 2.9 kW
- Alternator (non-AC), 1.6 kW
- Air Compressor, 0.6 kW
Total: 19.3 kW

How much could we gain through accessory electrification?
Estimating Potential Savings

• Assumptions
  – Electrical accessories at idling power of mechanically-driven counterparts
  – Provides enough power to perform accessory’s function at all times
  – Accessories decouple from engine speed when not needed

<table>
<thead>
<tr>
<th></th>
<th>Original Average Input Power (kW)</th>
<th>Theoretical Average Input Power (kW)</th>
<th>Average Load Reduction (kW)</th>
<th>Average Load Reduction (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engine Fan Pump</td>
<td>6.3</td>
<td>3.2</td>
<td>3.1</td>
<td>49%</td>
</tr>
<tr>
<td>Power Steering Pump</td>
<td>1.8</td>
<td>1.2</td>
<td>0.6</td>
<td>34%</td>
</tr>
<tr>
<td>AC Compressor</td>
<td>0 / 6.1</td>
<td>0 / 4.1</td>
<td>0 / 4.1</td>
<td>33%</td>
</tr>
<tr>
<td>Air Compressor</td>
<td>0.58</td>
<td>0.29</td>
<td>0.29</td>
<td>50%</td>
</tr>
<tr>
<td>Alternator</td>
<td>2.3 / 4.5</td>
<td>2.3 / 4.5</td>
<td>0</td>
<td>0%</td>
</tr>
<tr>
<td>Total</td>
<td>11.0 / 19.3</td>
<td>7.0 / 13.3</td>
<td>4.0 / 6.3</td>
<td>36% / 31%</td>
</tr>
</tbody>
</table>

Engine fan and AC drive account for about 80% of potential savings!
Conclusions – Potential savings through accessory electrification

• Complete electrification of accessories could lead to 13-15% fuel savings
• Engine fan electrification should lead to a 5-10% improvement
• CO$_2$ emissions reductions = fuel savings
Next Steps

• Extend audit to 3 types of buses in the Metro Transit bus fleet
  – Standard diesel bus
  – Parallel hybrid bus
  – Fully electrified series hybrid bus

• Develop methods to analyze the collected data and methods to link it to data collected by Metro Transit.

• Use analyzed data to improve and calibrate models of bus performance and emissions.

• Examining the utility of using auxiliary power units (APUs) to generate this energy

• Installing and testing a high efficiency Diesel APU and eventually a solid oxide fuel cell APU
Questions?

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