Evaluation of Electric Buses

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Aalto research in ECV-eBus

Modeling and simulation
• Dimensioning powertrain components
• Evaluating performance and energy consumption
• Thermal management of powertrain components

Comparison of powertrain technologies
• Different electric powertrain configurations
• Different powertrain technologies
  • Diesel, CNG, Parallel and series hybrid, Fuel cell hybrid, Electric
  • Energy consumption and cost effectiveness
Research challenges

Minimizing energy consumption
- Energy efficient powertrain and auxiliary devices
- Thermal management of components and interior space
  → Modeling, simulation and prototype testing

Costs effective operation
- Battery capacity vs. charging method and power capacity
- Operation and fleet management
  → Electric bus route simulation
Alternatives for electric powertrains (1/2)

A) Battery and a single traction motor
B) Battery, a single traction motor and a multi-gear transmission
C) Battery and two traction motors with a single-gear transmission
D) Battery, ultracapacitors and a single traction motor

Energy consumption comparison

Alternatives for electric powertrains (2/2)

A) Single traction motor and a final drive
B) Single traction motor, two-speed gearbox and a final drive
C) Two separate traction motors with reduction gears
D) Two separate in-wheel traction motors on rear wheels
E) Four separate in-wheel traction motors

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Distribution of energy losses

**Diesel bus**

Energy consumption: 37 kWh (3.64 kWh/km)

- Engine: 2220 Wh/km (61%)
- Accessories: 480 Wh/km (13%)
- Transmission: 130 Wh/km (3%)
- Tyres: 350 Wh/km (10%)
- Brake: 370 Wh/km (10%)
- Aero: 90 Wh/km (3%)

**Electric bus**

Energy consumption: 10.5 kWh (1.02 kWh/km)

- Battery: 20 Wh/km (2%)
- Accessories: 90 Wh/km (9%)
- Transmission: 350 Wh/km (35%)
- Tyres: 270 Wh/km (26%)
- Brake: 20 Wh/km (2%)
- Aero: 270 Wh/km (26%)

Espoo 11 cycle, bus total weight = 14250 kg, moderate auxiliary power consumption
Energy consumption comparison

Comparison of six different powertrain technologies:
CONV = Diesel
PAR_1 = Parallel Hybrid (Ucap)
PAR_2 = Parallel Hybrid (Batt)
SER_1 = Series Hybrid
SER_2 = Series Hybrid (Plug-In)
EV = Battery Electric

Energy consumption decrease on average

Lifecyle cost

Cost parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diesel city bus capital cost (€)</td>
<td>225000</td>
</tr>
<tr>
<td>Diesel fuel cost without VAT (€/l)</td>
<td>1.185</td>
</tr>
<tr>
<td>Electricity cost without VAT (€/kWh)</td>
<td>0.10</td>
</tr>
<tr>
<td>Maintenance cost for diesel bus (€/km)</td>
<td>0.14</td>
</tr>
<tr>
<td>High power battery cost (€/kWh)</td>
<td>1000</td>
</tr>
<tr>
<td>High energy battery cost (€/kWh)</td>
<td>750</td>
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<tr>
<td>Ultracapacitor system cost (€)</td>
<td>15000</td>
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<tr>
<td>Operation time in a year (h)</td>
<td>4000</td>
</tr>
<tr>
<td>Service life in years</td>
<td>12</td>
</tr>
<tr>
<td>Discount rate (%)</td>
<td>7</td>
</tr>
</tbody>
</table>

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Cost effectiveness

Capital and energy storage costs have the major impact on the cost effectiveness of hybrid and electric buses.

Ongoing research

Electric bus route simulations

1. What kind of electric buses should be selected for achieving energy and cost efficient operation in given operating conditions?
2. How to define requirements of the charging infrastructure for the operation of electric buses?

Comparisons of city buses

- Energy consumption, costs and CO$_2$ emissions (with UC Berkeley)
- Including Natural Gas and Fuel Cell hybrid buses
- Finland and California as case studies for costs and CO$_2$ emissions
- Manuscript to be submitted in March 2015
CO₂ emission results (case Finland)

Energy pathways for Finland

<table>
<thead>
<tr>
<th>Energy</th>
<th>Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diesel</td>
<td>(Edwards et al., 2013)</td>
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<tr>
<td>Natural gas</td>
<td>CNG imported by pipeline</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>Reforming on-site from CNG</td>
</tr>
<tr>
<td>Electricity</td>
<td>Finnish electric grid mix</td>
</tr>
</tbody>
</table>

Electric buses have potential to decrease CO₂ emissions more than 85% in comparison to diesel buses

Summary

- Electric city buses have a significant potential to increase energy efficiency and decrease CO$_2$ emissions
- High purchase cost is the main barrier for the electric buses
- Thermal management is a challenge which needs dedicated research and advanced solutions
- Electric city buses can be more cost efficient than diesel buses already in the near future
Related publications