ELIPTIC Use Case Eberswalde

Extension of trolleybus operation
Methodology and Results

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Introduction

Eberswalde

- Approx. 39,000 inhabitants
- County Seat
- 1 out of 3 German trolleybus towns
- Elongated urban structure

- Eliptic Use Case on hybrid trolleybus operation
Introduction
The existing trolleybus network

861 Nordend
(18.8 km)

862 Ostend
(18.1 km)

BBG bus depot
Introduction
The diesel bus line 910

- Partly parallel to the trolleybus lines
- Length: approx. 14.7 km (depending on terminal stop in Finowfurt)
- Connects neighbouring Finowfurt with Eberswalde
The Use Case

Extension of trolleybus operation

- By combining line 910 with the trolleybus catenary network
- Use of trolleybuses with energy storage instead of APU
- Minimum extension of the catenary network
The vehicles
Pre-configured Solaris trolleybuses

- 12 buses in operation
- One bus already equipped with a battery
- Retrofitting of additional buses – subject to feasibility study
- Recharging under catenary
The vehicles
Pre-configured Solaris trolleybuses

- Length / total weight: 18 m / max. 28 t
- Driven axle: 2\textsuperscript{nd}, asynchronous motor
- Power (con. / max.): 250 / 300 kW
- Torque (con. / max.): 1734 / 2600 Nm
The vehicles
Pre-configured Solaris trolleybuses

- Battery: LiFePO4
- Energy content: 70.4 kWh (42.2 kWh usable)
- Weight: 1020 kg
- Power: 38 kW (charging) / 140 kW (discharging)
The vehicles
Pre-configured Solaris trolleybuses

- Braking energy storage: Super capacitors
- Energy content: 0.57 kWh
- Average power: 150 kW (discharging)
Feasibility study
Technical feasibility

- Vehicle simulation
- Based on measured speed-distance-patterns
- Using Fraunhofer IVIvision vehicle simulation model
Feasibility study
Core questions

• Is the battery big enough to cover the catenary free section to/from Finowfurt?
• Is there enough time under the catenaries to recharge the battery?
Feasibility study
Secondary questions

• How long must the additional catenary be?
• Is a charging station at the terminal stop in Finowfurt necessary?
• Are additional trolleybuses necessary? ⇒ Yes, pre-decided by BBG!
Feasibility study
Approach

- Field measurements:
  - speed-distance-patterns / speed-time-patterns
  - passenger demand
- Configured vehicle model and catenary network using IVision
- Vehicle simulations using schedules provided by BBG
## Catenary

### 4 Layouts

<table>
<thead>
<tr>
<th>Layout</th>
<th>Extension to the west</th>
<th>Extension to the east</th>
</tr>
</thead>
<tbody>
<tr>
<td>O1 Existing catenary</td>
<td>Kleiner Stern</td>
<td>-</td>
</tr>
<tr>
<td>O2 Extension west</td>
<td>Großer Stern</td>
<td>-</td>
</tr>
<tr>
<td>O3 Extension east #1</td>
<td>Großer Stern</td>
<td>Tramper Chaussee</td>
</tr>
<tr>
<td>O4 Extension east #2</td>
<td>Großer Stern</td>
<td>Bernauer Heerstrasse</td>
</tr>
</tbody>
</table>

- max. electric power taken from catenary at 600 V
  - while driving: 400 A; 240 kW (could be higher)
  - during stops: 150 A; 90 kW
### Vehicle Parameters

**HVAC**

<table>
<thead>
<tr>
<th>Version</th>
<th>Component</th>
<th>Installed heating / AC power</th>
</tr>
</thead>
<tbody>
<tr>
<td>K 1</td>
<td>Heat pump</td>
<td>Heating 2x 30 kW</td>
</tr>
<tr>
<td></td>
<td></td>
<td>AC 2x 24 kW</td>
</tr>
<tr>
<td></td>
<td>Electric heater</td>
<td>Heating 38 kW</td>
</tr>
<tr>
<td>K 2</td>
<td>Diesel heater</td>
<td>Heating 50 kW</td>
</tr>
<tr>
<td></td>
<td>24 V-AC unit</td>
<td>AC 3 x 5 kW</td>
</tr>
</tbody>
</table>

- **Objective:** Fully electric operation!
## Ambient Conditions

### 3 Scenarios

<table>
<thead>
<tr>
<th>Ambient Conditions</th>
<th>Temperature</th>
<th>Solar Irradiation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scenario S1</td>
<td>-24°C to -17°C</td>
<td>overcast</td>
</tr>
<tr>
<td>Scenario S2</td>
<td>15°C to 17°C</td>
<td>overcast</td>
</tr>
<tr>
<td>Scenario S3</td>
<td>23°C to 36°C</td>
<td>sunny</td>
</tr>
</tbody>
</table>

- „worst case“ Scenarios (S1 and S3)
  - safe operation in the winter time
  - determination of the highest energy demand
Boundary Conditions
Vehicles and passengers

• Vehicles
  ➢ 3 schedules
  ➢ L910_11: starts 4:17 Uhr; 19.5 h; 350 km
  ➢ L910_12: starts 5:47 Uhr; 14 h; 260 km
  ➢ L910_53: starts 5:17 Uhr; 19.5 h; 350 km

• Number of passengers: 2 scenarios
  ➢ constant 25 / 75 passengers
  ➢ per passenger: 50 – 100 W heat emission
  ➢ heat losses influenced by the duration of opened doors
  ➢ journeys to and from bus depot without passengers
Results
Energy consumption

Energy Consumption
Specific energy consumption [kWh/km]

- 0.00  0.50  1.00  1.50  2.00  2.50  3.00  3.50  4.00

S1
K1 S2
S3
electric heating
diesel heater

K2 S2
S3

- 200.0  400.0  600.0  800.0  1000.0  1200.0  1400.0

Energy Consumption [kWh]

Results Energy consumption
Results
State of Charge

- Electric heating – mild weather conditions (S2)
Results
State of Charge

• Electric heating – cold weather conditions (S1)

![Graph showing state of charge over time with specific energy consumption of 2.8 h! at Finowfurt, Südend, and Finowfurt.]
Conclusions
Answers to the questions

• Is the battery big enough to cover the catenary free section to / from Finowfurt?
  Yes!

• Is there enough time under the catenaries to recharge the battery?
  No! Charging power (38 kW) too low!

• How long must the additional catenary be?
  Longer than possible!

• Is a charging station at the terminal stop in Finowfurt necessary?
  It would help, but very high investment cost.
Conclusions Solution

- Battery with higher charging power
- Elimination of the supercapacitor storage
- Use of the SC-converter to recharge the battery
- Battery charging power and usable energy content to be determined in additional analysis.
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