Design of Electric Bus Systems

ebusplan GmbH

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Introduction: ebusplan

Challenges for the electrification of local public transport buses

Our solution – software based planning process

Summary
Introduction: ebusplan
RWTH Aachen ISEA – Power Electronics, Electrical Drives, Battery Systems

- RWTH Aachen ISEA
  - > 100 Research associates
  - > 120 Students

- Battery Systems (Prof. Sauer):
  - One of the largest university-bound research groups for battery systems in Europe
  - Extensive test capacities for battery cells and packs
  - Modelling, battery pack development, BMS, diagnostics
  - Electric drivetrains

- Segment Local Public Transport:
  - Topics: Dimensioning, Simulation, Evaluation
  - Projects: H2-Bus-NRW, SEB / EÖPNV, ZeEUS, ELIPTIC, Mun-E-P 1 & 2, LoCarUT, Industry projects

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Projects
SEB E-ÖPNV and ZeEUS

- Idea:
  - Charging with up to 500 kW
  - For several minutes
  - To facilitate the integration of charging events into bus runs

Source: Pintsch-Bamag
Spin-Off from ISEA of RWTH Aachen: “ebusplan GmbH“

- Technical Expertise, Experiences and Software Tools made available for:
  - Public Transport Operators (PTO)
  - Cities / Transport Authorities (PTA)
  - Bus manufacturers
  - Consultants

- Portfolio:
  - Feasibility studies
  - Development of detailed electrification concepts (also for large scenarios with multiple bus lines and many vehicles)
  - Trainings und workshops
  - Software solutions (to come)
Our Portfolio - From the First Move to the Concrete Implementation Concept

- **On-Site Workshops**
  - Quick start into the topic “electric buses” (technology, costs, realistic expectations of the technology)
  - Involvement of local stakeholders (e.g. operator, authority, politics), creation of a common basis for further planning and decision making

- **Feasibility Studies**
  - Analysis of local-specific operational conditions
  - Identification of routes to start electrification with
  - Economic and ecologic impacts of electric buses

- **Development of Concrete Electrification Concepts**
  - Software tool to continuously support the local planning process and enable coping with changing framework conditions
Challenges of electrification of LPT buses
**Planning and specification** of the operation and of the technical system

- Decisive issues:
  - Energy consumption?
  - Driving range of the vehicles?
  - Battery size?
  - Strategic positioning of the charging stations?
  - Required charging power?
  - Electricity grid available?
  - Costs?
  - Integration of charging phases into operations?
  - Planning of vehicle schedules (bus runs)?
  - Route changing bus runs?

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Different Approaches for the Introduction of Electric Buses

- „Trial & Error“ → expensive, time-consuming

- “Limit daily mileage to 100…200 km and use ‘Overnight Charging’ ” → Substantial changes in bus operation required (additional vehicles, additional personnel time)
  → How to determine the limit for the bus runs?
    Trial and error? Rely on manufacturer specifications?

- “Manual dimensioning” of technical system under consideration of
  - Frequencies (intervals) and dwell times at terminal stops (incl. buffer for delay)
  - Route characteristics, heights profile, …
  - Occupancy rates
  - Consumption of Heating / A/C
  - Available battery types (power, energy, durability/guarantee, costs, …)
  - Availability and costs of electricity grid and building ground for charging stations
    - energy consumption (normal case VS worst case)
  - Many more …
Our approach: Software-supported planning process
Dedicated Software Tool
“Electrification Planner”

- Detailed simulation of the entire operation (all single trips)

- Definition & evaluation of various configurations
  - Location and power of charging stations
  - Battery technology and size
  - Evaluation of technical feasibility and costs

  ➔ The approach makes transparent the impact of decisions

- Optimization algorithms finds scenario with lowest Total Costs of Ownership

  ➔ The approach tailors solutions to the specific local requirements
Example for the simulation of bus operation:
Detailed entire-day profiles for each vehicle and charging station

- Charging station at terminal stop A
- Charging station at terminal stop D
- Bus garage

Schedule: “Veh3“

Power offered (kW), Vehicle status, State of Charge (%)
Optimisation algorithm calculates many different configurations (charging stations and vehicle battery capacities)
System Design
Exemplary Results of Optimisation

Cost shares

- Vehicles: 55%
- Infrastructure: 24%
- Energy: 21%

<table>
<thead>
<tr>
<th>Optimisation variable</th>
<th>Optimised value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Battery capacity</td>
<td>125 kWh</td>
</tr>
<tr>
<td>Terminal stop A</td>
<td>125 kW</td>
</tr>
<tr>
<td>Terminal stop B</td>
<td>0 kW</td>
</tr>
<tr>
<td>Terminal stop C</td>
<td>0 kW</td>
</tr>
<tr>
<td>Terminal stop D</td>
<td>270 kW</td>
</tr>
<tr>
<td>Terminal stop E</td>
<td>0 kW</td>
</tr>
<tr>
<td>Depot / garage</td>
<td>1 x 100 kW</td>
</tr>
</tbody>
</table>
Allocation of Costs
Possible Synergies Regarding Infrastructure

Small scenario
- Vehicles: 55%
- Infrastructure: 24%
- Energy: 21%

Medium scenario
- Vehicles: 61%
- Infrastructure: 29%
- Energy: 10%

⇒ Shrinking share of infrastructure costs
Parameter Variation and Typical Scenarios to Evaluate

- What if …
  - …the specific energy of the battery increases in near future?
  - …the costs for the battery system decreases in near future?

- Comparison of different battery systems with different performance
  - High Energy VS High Power
  - NMC, LFP, LTO
  - Different durability / different guarantee periods

- How would the system look like when heating is powered by…
  - …the battery system?
  - …an additional fuel heater?

- Variation of basically any parameter possible (e.g. electricity cost, …)
**Our Approach: Software-Supported Planning**

- Frequent and easy re-calculation → efficiency increase in planning process

**Graphical Representation:**
- **PTA (Public Transport Authority)**
- **PTO (Public Transport Operator)**
- **El. Grid Operator**
- **City / Municipality**

**Interactions:**
- LCC calculator
- Optimization algorithm
- Sensitivity Analysis
- Models of vehicle and driver

**Input:**
- Operational conditions (e.g., vehicle schedules)
- Availability and costs of grid connection

**Output:**
- Available space for charging infrastructure

**Suppliers:**
- Supplier (bus manufacturer, charging infrastructure, battery supplier)

**PTO:** Public transport operator
**PTA:** Public transport authority
Software tools, project experience and state of the art knowledge are combined within the ebusplan consultancy service.

Software-based planning approach
- evaluates and compares electrification concepts prior to expensive investments
- finds cost advantages over “manual” system design (by optimization)
- reduces complexity and therefore enables handling highly complex scenarios (e.g. not only single bus lines)
- enables fast and efficient coping with changing framework conditions
- provides a transparent basis for negotiations between the involved local stakeholders (e.g. by concrete load profiles for vehicles and charging infrastructure).

Planning efficiency, transparency and reliability
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