Scenario Analyses of a Dynamic LVDC Smart-Trolleybus-Network with Battery-Assisted Traction Loads

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3rd E-Mobility Power System Integration Symposium
Introduction
Project “BOB¹ Solingen”

- New Components
  - Battery-Trolleybuses (BOBs)
  - Photovoltaic Systems (PV)
  - Electric Vehicle Charging Stations (EV)
  - Stat. Storage Systems
  - Bi-directional Substations

- Simulation Tool
  - Traffic Network Model
  - Electrical Network Model
    (Low Voltage Direct Current Traction Network)
  - Buses Model (Trolleybuses, BOBs)
  - Network state calculation (Power Flow Analysis)

- Grid State Identification
- Intelligent Grid Control (Load Forecast)

Infrastructure before Project Start:
- \( V_{nom} = 660 \, V_{DC} \)
- 22 Unidirectional Substations
- \( \approx 50 \) Trolleybuses
- \( \approx 50 \) Diesel Buses
- Catenary length \( \approx 100 \, km \)

¹ German Abbreviation for: Battery-Trolleybus
Simulation: Workflow

Traffic Network/ Electrical Network

Start → Initialization

Bus Timetable

Input Parameters
Simulation: Workflow

Start → Initialization

- Power Profile EV
- Power Profile PV

Characteristic EV Power Profile:

Characteristic PV Power Profile:
Simulation: Workflow

Bus Power Profile:

- Power Profile EV
- Power Profile PV

Start → Initialization → Power Profile EV → Power Profile PV → Bus Movement
Simulation: Workflow

Start → Initialization → Power Profile EV → Power Profile PV

Increasing Time

Bus Movement → Read EV Power → Read PV Power

Power Flow Calculation → Simulation finished?

End
Simulation: Workflow

Current Flow Visualization:
Simulation: Use-Cases

- Live-Monitoring and Forecasting for an Intelligent Grid Control
- Optimal Sizing of
  - Photovoltaic Systems
  - Stat. Storage Systems
- Optimal Positioning of
  - EV Charging Stations
  - Photovoltaic Systems
  - Stat. Storage Systems
- Scenario Analyses
  - Present and Future Scenarios
  - Identification of Suitable Bus Lines for BOB Usage
Identification of Suitable Bus Lines for BOB Usage

Bus line 695:
- Charging Point will be installed at Terminal Stop
- Suitable for BOB Usage

\[ \Delta \text{SoC} \approx 45\% \]
\[ \Delta \text{SoC} = 3 - 5\% \]
\[ \text{SoC}_{min} \approx 9\% \]
Identification of Suitable Bus Lines for BOB Usage

- Bus line 683:
  - Actually a Trolleybus Line
  - Suitable for BOB Usage

Bus line with catenary
Bus line without catenary

Bus Depot
Identification of Suitable Bus Lines for BOB Usage

- Bus lines 698 & 692:
  - Increased Waiting Times under the Catenary, Installation of a Charging Point or Restructuring of the Bus Lines necessary
  - Otherwise not suitable for BOB Usage
### Scenario Analyses

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Bus Number</th>
<th>Trolleybuses</th>
<th>BOBs</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>46</td>
<td>0</td>
<td>54</td>
<td>Only Trolleybuses</td>
</tr>
<tr>
<td>II</td>
<td>46</td>
<td>5</td>
<td></td>
<td>5 BOBs replacing Diesel Buses*</td>
</tr>
<tr>
<td>IIIa</td>
<td>46</td>
<td>69</td>
<td></td>
<td>All Diesel Buses replaced by BOBs</td>
</tr>
<tr>
<td>IIIb</td>
<td>46</td>
<td>43</td>
<td></td>
<td>Diesel Buses will only be replaced on suitable BOB Routes</td>
</tr>
</tbody>
</table>

* BOBs will replace Diesel Buses on Bus Line 695 in the Future
Scenario Analyses

- Extremely high cumulative Power Increase
- Rush-hour Traffic clearly recognizable
- Charging Peak Load in the Evening
### Scenario Analyses

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<td>43</td>
</tr>
<tr>
<td>Summed “burned” Braking Energy (kWh)</td>
<td>58.83</td>
<td>54.93</td>
<td>41.23</td>
<td>56.50</td>
</tr>
<tr>
<td>Average “burned” Braking Energy (kWh)</td>
<td>1.28</td>
<td>1.08</td>
<td>0.36</td>
<td>0.63</td>
</tr>
<tr>
<td>Summed System Losses (MWh)</td>
<td>1.60</td>
<td>1.80</td>
<td>3.46</td>
<td>2.54</td>
</tr>
<tr>
<td>Average System Losses per Bus (kWh)</td>
<td>34.69</td>
<td>35.39</td>
<td>30.07</td>
<td>28.58</td>
</tr>
</tbody>
</table>

- More regenerative Bus Braking Energy is burned, but the average burned Energy per Bus decreases.
Conclusion & Future Work

- Future Scenarios show how the Trolleybus System will develop in the Future
- Substations Power Profiles show the Consequence of a worsened Network State
- An Analysis of different Future Scenarios shows how BOB Usage is possible
- Many Diesel Bus Lines do not offer a switch from Diesel Buses to BOBs
- A Restructuring of the Bus Lines is necessary to integrate more BOBs.
Conclusion & Future Work

- The Simulation offers the Possibility to perform live Monitoring and Forecasting for the DC Network
- Future Papers will focus on Optimizing the Forecast
Thank you for your Attention!
Questions?