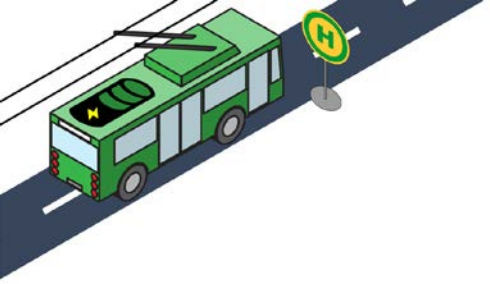

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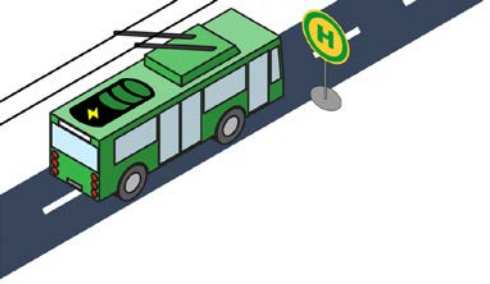
Modelling and Simulation of a Public Transport System with Battery-trolleybuses for an Efficient E-mobility Integration

University of Wuppertal
Chair of Power System Engineering
Univ.-Prof. Dr.-Ing. M. Zdrallek
Research Group:
Smart Grids and Smart Systems

Dirk Baumeister (Research Assistant)

1st E-Mobility Power System Integration Symposium



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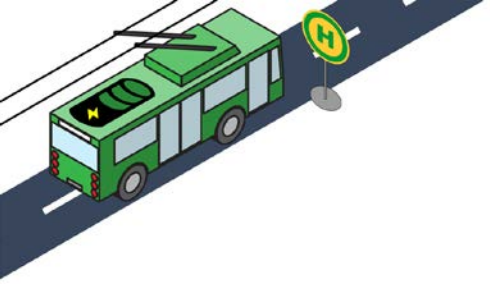
Structure

- Introduction
- Bus Power Profile
- Simulation Results
- Conclusion & Future Work



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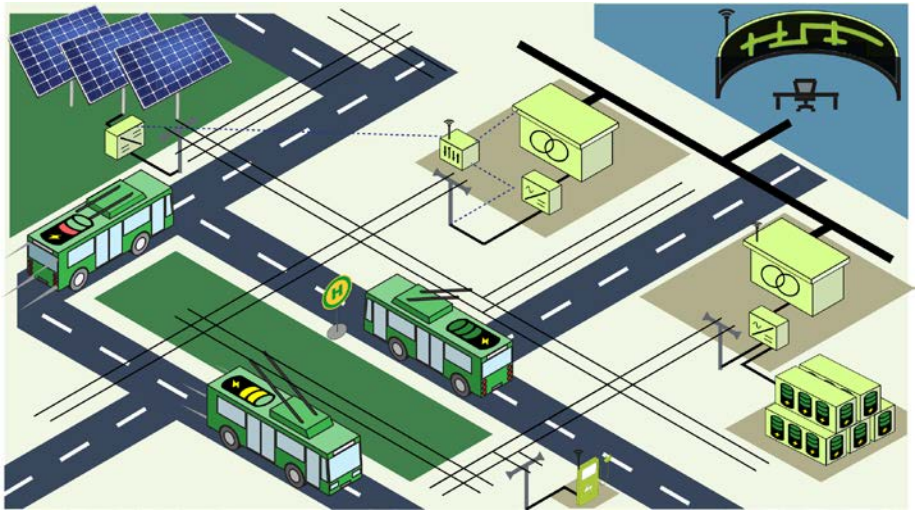
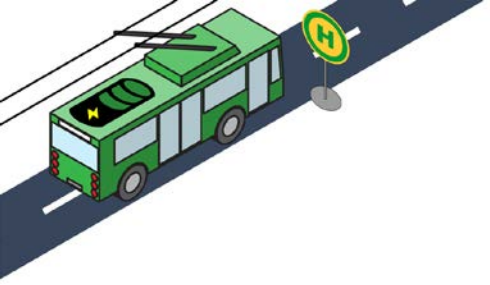
Introduction

- Solingen owns a trolleybus systems with 50 electrically powered trolleybuses containing auxiliary diesel engines
- The aim of the project "BOB Solingen" is to electrify public transport
- Integration of battery-trolleybuses (BOB)



- The BOB will combine proven trolleybus technology with the latest battery technology
- The BOB are able to perform emission free operating even on lines with partly uncovered power supply



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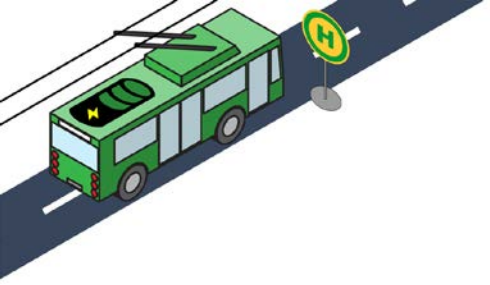

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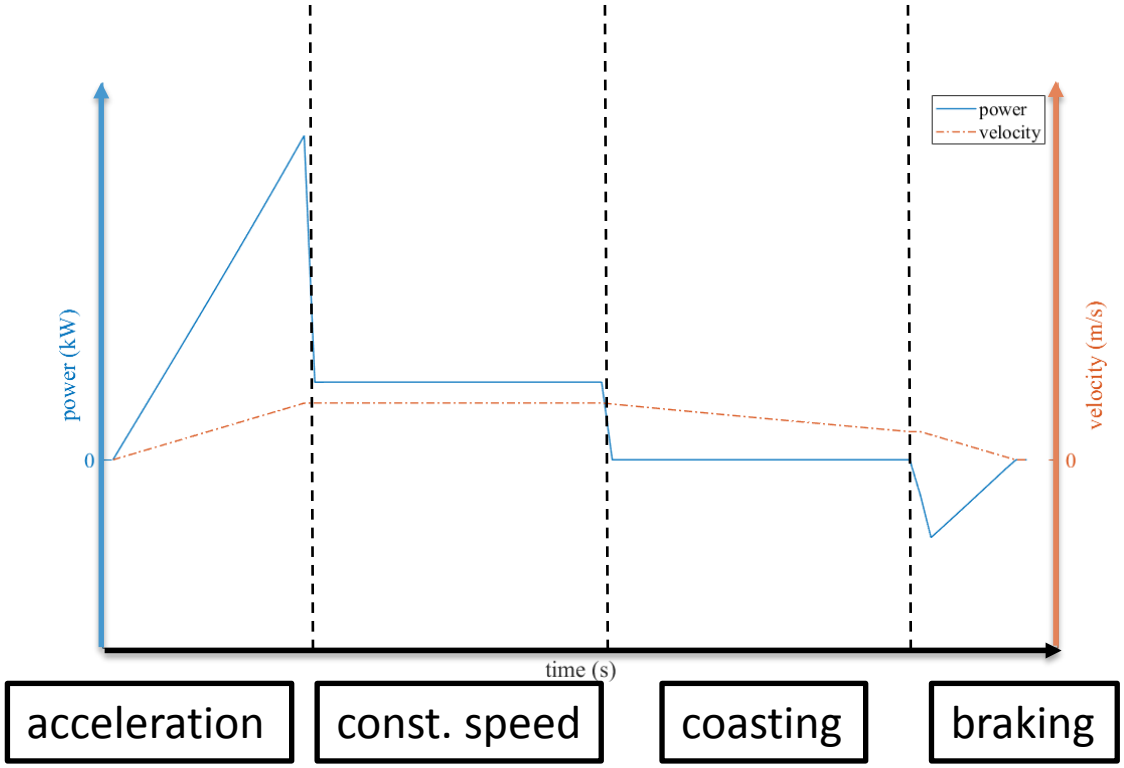
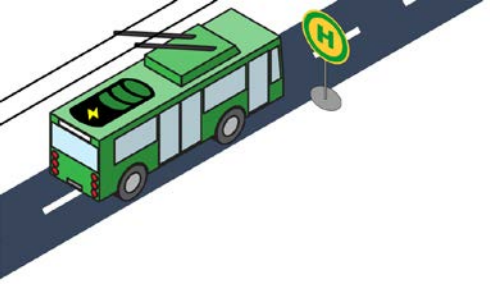
Bus Power Profile

Bus speed and power profile



- For a future load flow calculation, a realistic bus profile is required
- Introduction of four different driving modes
- Consider bus information (e.g. engine power)



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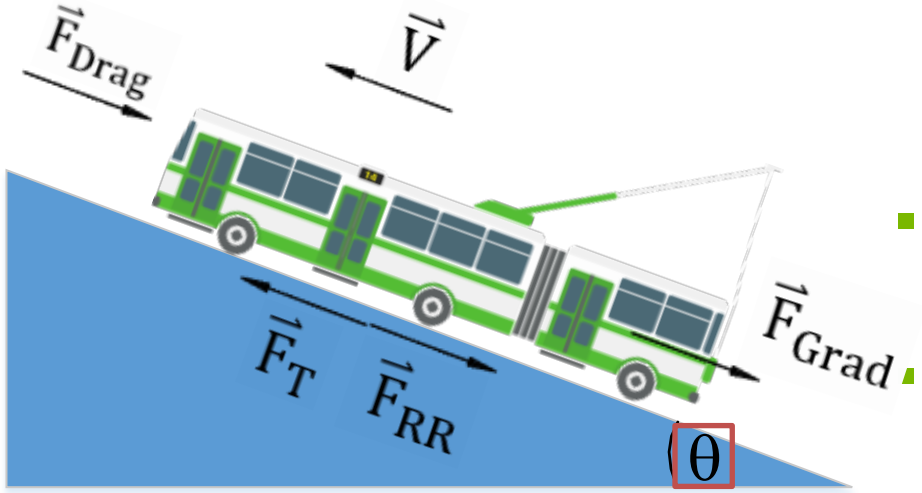
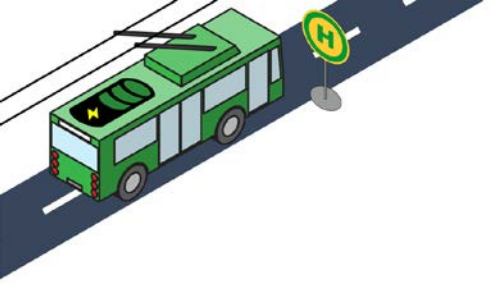
Bus Power Profile

Occurring forces while driving



- Acceleration:
  - $\vec{F}_T = \boxed{m} \cdot \vec{a} + \vec{F}_R$
  - $\vec{F}_R = \vec{F}_{RR} + \vec{F}_{Grad} + \vec{F}_{Drag}$
  - $P_M = \vec{F}_T \cdot \vec{V}$
  - $\boxed{P_E} = \frac{P_M}{\eta}$
- Constant Speed:
  - $\vec{a} = 0 \Rightarrow \vec{F}_T = \vec{F}_R$
- Coasting:
  - $\vec{F}_T = 0 \Rightarrow \vec{a} = -\frac{\vec{F}_R}{\boxed{m}}$
- Braking:
  - Bus decelerates until $\vec{V} = 0$

Depends on topology (θ), mass (m) and a limited engine power ($P_{E,max}$)



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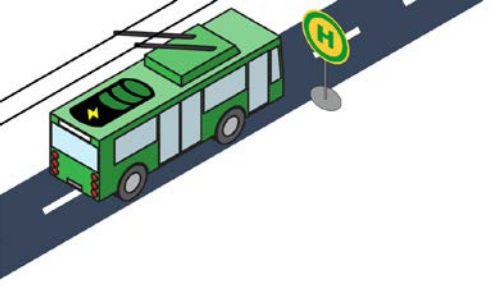

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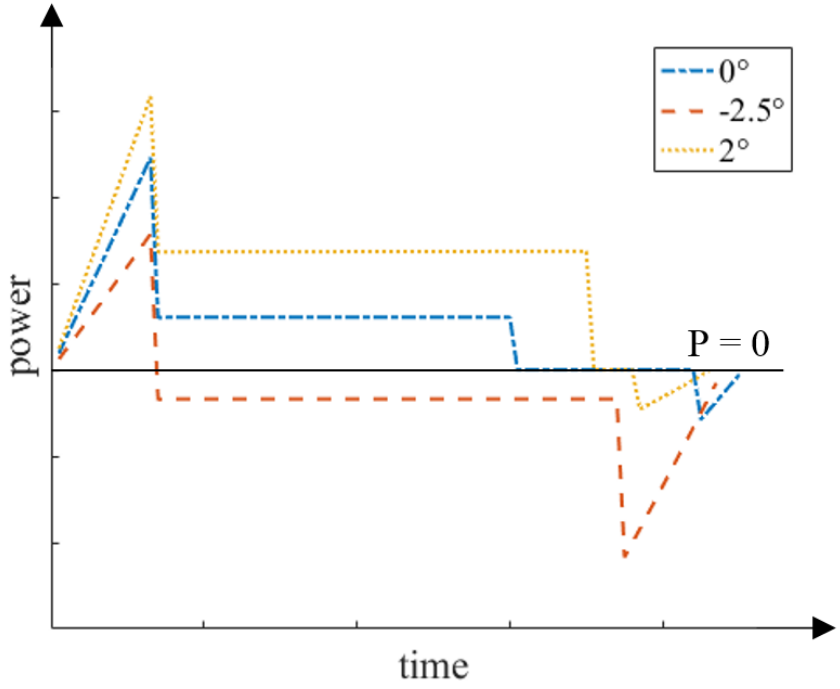
Simulation Results

Topology



- The topology has a big influence on the bus power
- Even small changes of the angle (θ) lead to highly varying power profiles

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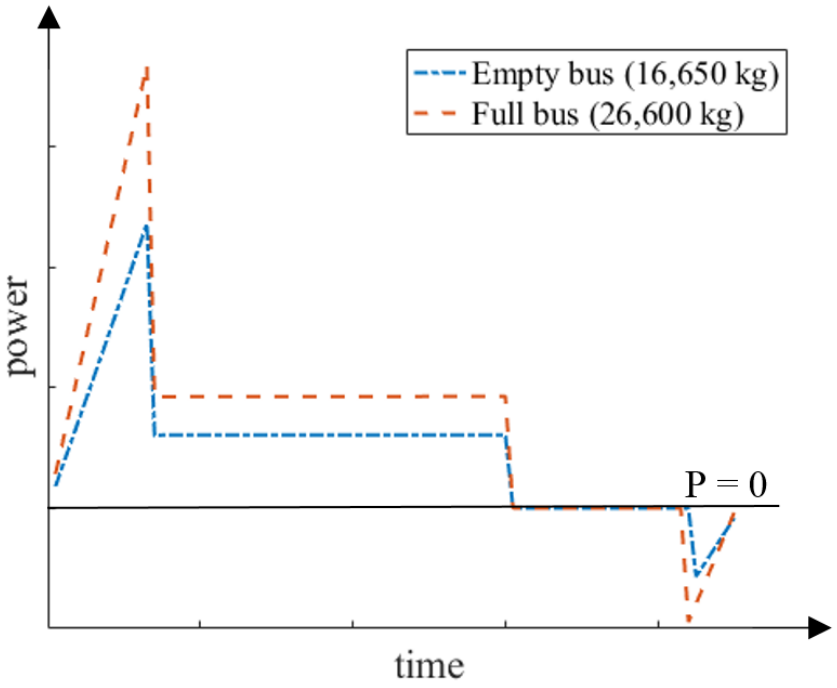
Simulation Results

Mass



- The fully loaded bus requires more power and can also refeed more power while braking
- No time delay due to higher performance
  - Speed profiles of both buses are identical

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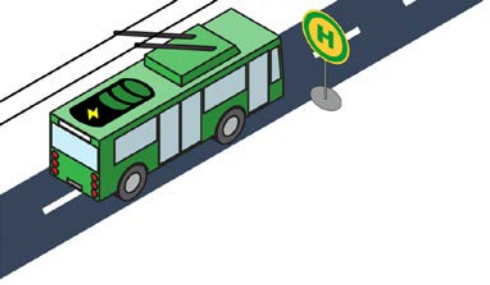
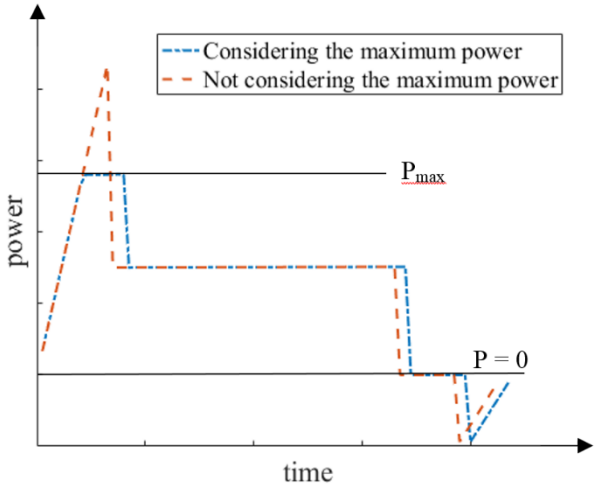
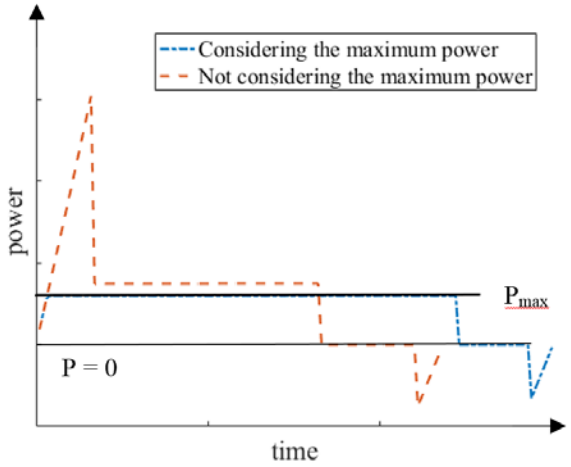


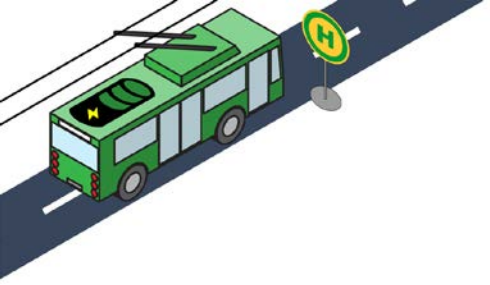
Simulation Results

Limited engine power





- The bus requires a lot of power when e.g. driving uphill
- When the required power exceeds the limit the acceleration will be reduced
- The time to reach the target speed increases or the target speed will be not achieved
- This results in a time delay



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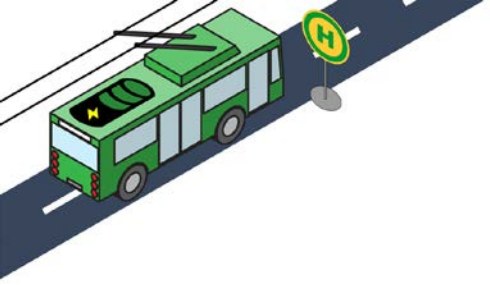
Simulation Results

Traffic

- Bus power also depends on the traffic situation
- Points where the bus stops or reduces speed are considered
  - Traffic lights
  - Bus stops
  - Bends
  - Junctions
  - Start/ End
- Speed limitations are also considered
- Introduction of traffic modes
  - The maximum speed is reduced according to the traffic mode



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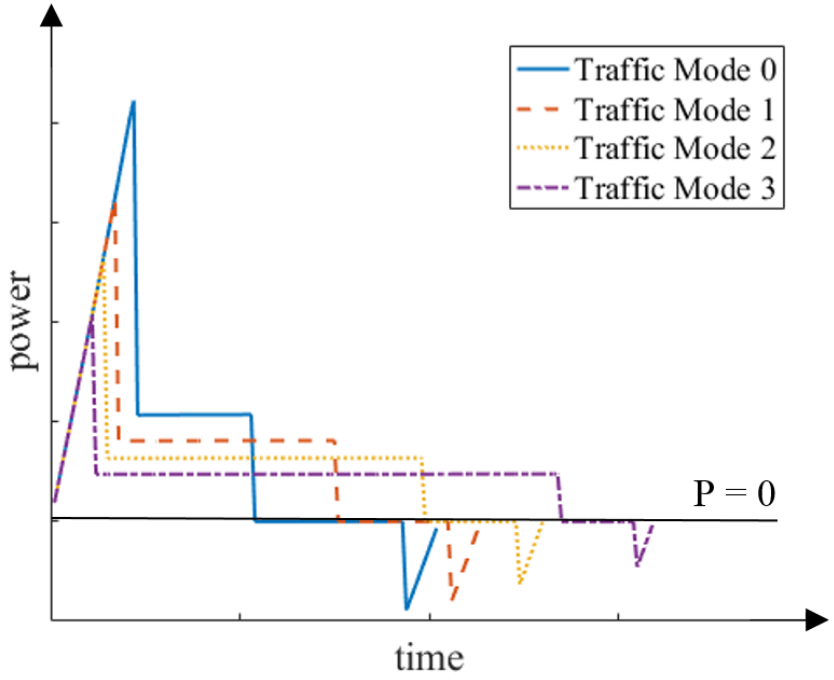
Simulation Results

Traffic



- A delay occurs depending on the traffic mode
- The maximum speed is reduced according to the traffic mode
  - No traffic ≙ Mode 0 (no reduction)
  - Low traffic ≙ Mode 1
  - Medium traffic ≙ Mode 2
  - High traffic ≙ Mode 3

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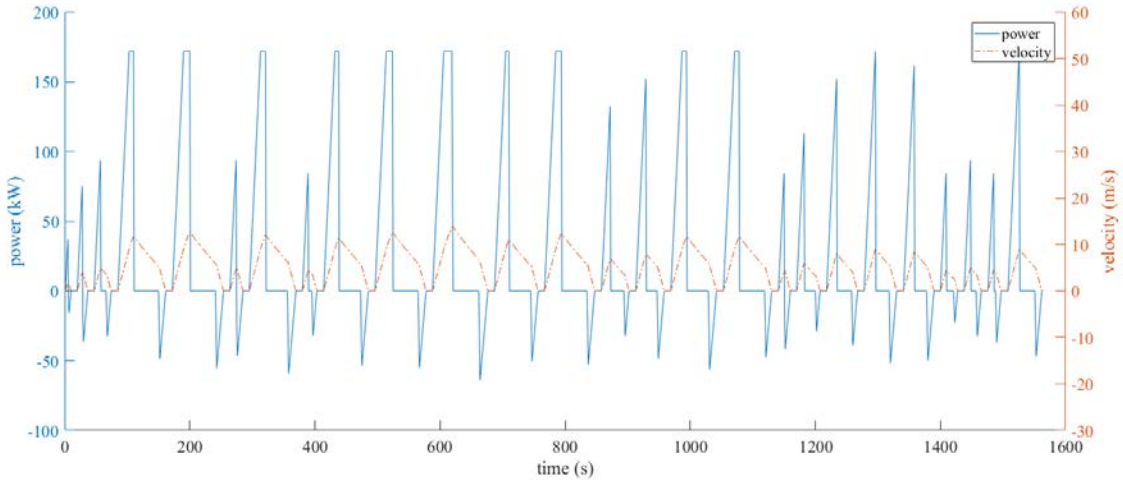
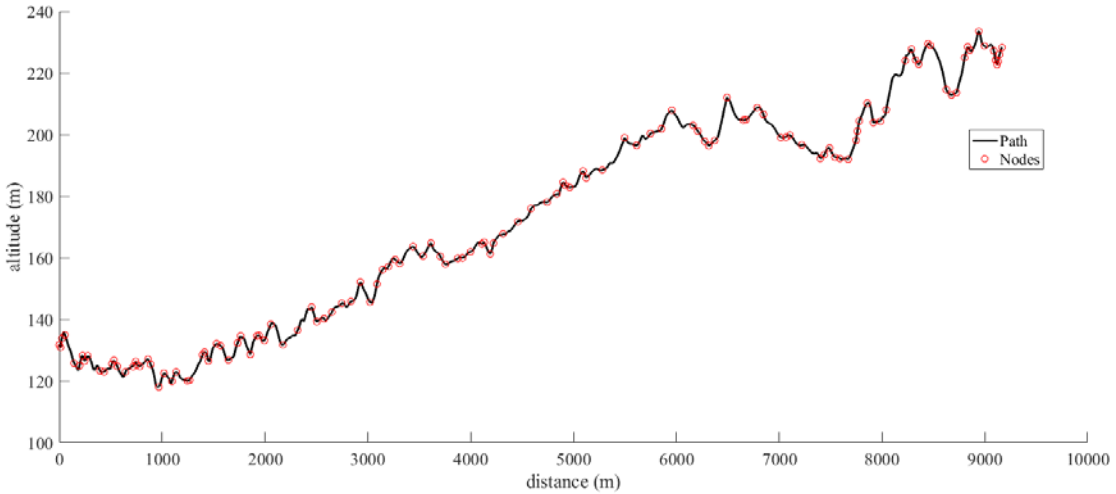
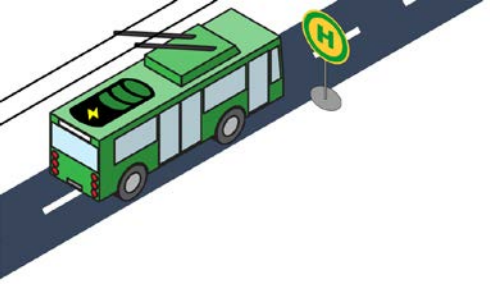
Simulation Results

Bus operation line power consumption





- Simulation of an entire bus route considering the height profile
- Calculation of the bus power for each time step
- Probabilities for stopping at traffic lights as well as acceleration of buses can be varied



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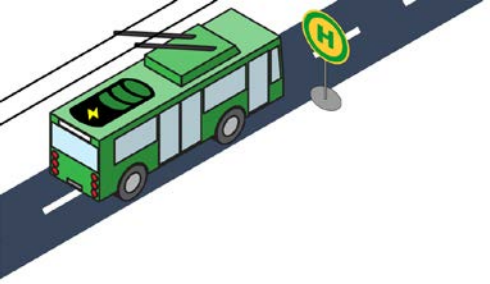

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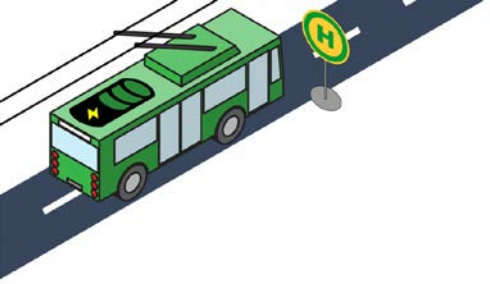
Conclusion & Future Work I

- Contributing factors (e.g. topology) are not negligible

- Other factors that may need to be considered
  - Stop-And-Go traffic
  - Temperature/ weather (affects the battery)
  - Driving behavior of bus drivers
- Bus Scheduling

- Implementation of
  - Battery-trolleybuses
  - Stationary storage
  - A photovoltaic system
  - Charging stations for electric vehicles



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Conclusion & Future Work II

- DC Load Flow Calculation ($U_{\_}$ = 750 V)
  - Every bus will be a (movable) node
  - Newton-Raphson vs. Gauss-Seidel
  - Validation of results
- Smart Trolley System (STS)
  - Automation system for the DC grid
  - Usage of the overhead infrastructure should be both effective and efficient as possible
  - Avoiding the conventional grid expansion measures
  - Intelligent (dis-)charging system
- Transfer Analysis (e.g. tram)

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Thank you for your Attention!
Questions?

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