energy efficiency increase of electrical local transport systems

recognise opportunities – evaluate effects

IT15.rail

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agenda

1. motivation
2. load flow of electrical railway power supply systems
3. co-simulation tool for holistic system analysis
4. energy efficiency increase by network optimization
5. project example
6. conclusion
electrical energy may be generated from renewable resources

⇒ traffic shall be powered by electrical energy

energy expense is a significant part of operating expense for operators

vehicle manufacturer and operator focus on energy efficiency increase

**target: to control future energy cost**

**main target:**
minimise energy consumption of transport

⇒ optimisation on component level

⇒ optimisation on system level (holistic approach)
motivation

Where is the billing?

AC 3~ 50 Hz  10/20/30 kV

transmission network at traction power substation

bulk station

vehicle
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Where does the power demand come from?

**rolling resistance**

+ distance resistance

**acceleration resistance**

**tractive effort**

\[ F_{R} = A + B \cdot v + C \cdot v^2 \]
Where does the power demand come from?

- traction component efficiency
- auxiliary power
- eddy current break
- energy storage (DC)
Where does the power demand come from?

time and position dependent consumers

network structure and voltage level controls the load flow

railway power supply system has impact on energy demand

load flow of electrical railway power supply systems
Where does the power demand come from?

low line voltage affects the vehicle traction
  – increasing currents and losses with decreasing line voltage
  – current, respectively power limitation, at low voltage ➔ increased travel time
  – limited energy recovery due to maximum line voltage limitation (no energy absorption by the network)

retroactive effects have to be considered during simulation
  – at AC less important due to usually stable line voltage
  – at DC it is mandatory due to high voltage fluctuation

simulation of railway power supply systems require simultaneous information of the following physical processes:
  – driving state of each train and power demand
  – position of all vehicles within the electrical network
  – structure and installed capacity of the railway power supply system
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co-simulation tool for holistic system analysis

Railway Operation Simulation

OPEN TRACK

“Co-Simulation”

ATM
Advanced Train Model

PSC
Power Supply Calculation

Interaction

Load Flow Simulation

openPowerNet

Propulsion Technology

Power Supply System
co-simulation tool for holistic system analysis

model verification, measurement and simulation at Zurich Public Transport

![Graph showing voltage and current over time](image)
Queensland Rail Proof of Concept – comparing energy demand

co-simulation tool for holistic system analysis

energy efficiency increase

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Martin Jacob

openPowerNet.de

www.bahntechnik.de
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energy efficiency increase by network optimization

characteristic values to assess energy efficiency

1. vehicle related recovery coefficient

\[ \zeta_{\text{vehicle}} = \frac{E_{\text{brake}} - E_{\text{auxiliary,brake}}}{E_{\text{traction}} + E_{\text{auxiliary,traction}}} \]

2. network related recovery coefficient

\[ \zeta_{\text{Netz}} = \frac{E_{\text{recovered}}}{E_{\text{mbr_required}}} \]

3. system related recovery coefficient

\[ \zeta_{\text{sys}} = \frac{E_{\text{recovered}}}{E_{\text{recovered}} + E_{\text{FS_supplied}}} \]
1. Network analysis at actual state for different operational scenarios (timetable)

2. evaluation of network optimization changes, e.g.
   – change of network structure and/or nominal voltage
   – change of feeding station no load voltage
   – integration of energy storage
   – comparison of different changes

3. analyse implication of the changes
   – efficiency of the changes (investment ↔ savings)
   – line voltage, rail-earth potential, short circuit currents, …
   – n-1 operation
   – actual equipment load compared to load capability

energy efficiency increase by network optimization
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new rollingstock
during test drives low voltage conditions noticed

VBZ: Be 5/6 „Cobra-Tram“
bi-articulated trolley bus

week point analysis and network optimization of 300 km tram and 220 km trolley bus system
application of new rollingstock – results

minimum line voltage at vehicle

listing measures
new feeding locations
shifting of section isolators
new feeder and return feeder
amended feeding concept
protection setting of section circuit breaker
project example #2

amendment of no load feeding voltage
influence of line voltage level to total energy consumption

class 481

sub network snipped S-Bahn Berlin
Increasing total energy with decreasing $U_0$, FS provided energy decreases!

There is a optimum reflecting energy consumption and all relevant boundary conditions.

Energy saving (849 V): 360-445 kWh / h ~7% provided energy

total energy consumed
provided energy by feeding stations (FS)
used braking energy, inclusive vehicle auxiliary power
recovered energy from vehicle to network
integration of mobile energy storages – results

30 % energy savings!?

Example of power traces

- power
- velocity
- power limit of traction motor
- potential recoverable mechanical power
- total mechanical braking power
- mechanical braking power which will be transferred into electrical power for recuperation or auxiliaries

14 % energy saving referring to potential recoverable mechanical power

2-5 % energy saving referring to total energy consumption of vehicle

50-120kWh per trip

→ type and dimensioning of energy storage
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• energy cost is and will be an important cost factor
  ➔ efficiency is important

• energy savings are possible at different subsystems
  ➔ holistic approach including all relevant subsystems

• impact of parameter changes easily checked in verified simulation software
  ➔ OpenTrack and OpenPowerNet as the basis of infrastructure investment decisions

• there are a lot of cheap measures to increase the energy efficiency

• it is worthwhile to have a closer look
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Equipment rating too generous

Optimum equipment rating

Equipment rating inadequate

- Load capability
- Load
- Rated Load

Duration of Load →