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
motivation

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).
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
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 $\Rightarrow$ 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

OPENTRACK

“Co-Simulation”

Load Flow Simulation

Propulsion Technology

Power Supply System
co-simulation tool for holistic system analysis

model verification, measurement and simulation at Zurich Public Transport

![Graph showing voltage, current, and time parameters.](image)

- Voltage [V]
- Current [A]
- Time [s]

- Tolerance U (EN 50163)
- U_{nenn}
- U_{TFZ_2099}
- U_{Tlz_Simu}
- I_{TFZ_2099}
- I_{Tlz_Simu}

2015-06-12 energy efficiency increase
Martin Jacob
Queensland Rail Proof of Concept – comparing energy demand
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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

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

3. system related recovery coefficient

\[ \zeta_{\text{sys}} = \frac{E_{\text{recovered}}}{E_{\text{recovered}} + E_{\text{FS_supplie}}} \]
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 $\Leftrightarrow$ savings)
   - line voltage, rail-earth potential, short circuit currents, …
   - n-1 operation
   - actual equipment load compared to load capability
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project example #1

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

sub network snipped S-Bahn Berlin

class 481
amendment of no load feeding voltage-results

Increasing total energy with decreasing $U_0$, FS provided energy decreases!

There is an 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
project example #3

integration of mobile energy storages – results

30 % energy savings!?

evaluation of potential savings

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

Example of power traces

-18000
-16000
-14000
-12000
-10000
-8000
-6000
-4000
-2000
0
0 20 40 60 80 100 120
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
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conclusion

• **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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