TECHNISCHE UNIVERSITÄT DRESDEN

Faculty of Transportation and Traffic Sciences „Friedrich List“, Chair for Electric Railways

Influence of the On-Board Electrical System for Efficiency Improvement of Electrical Vehicles

Speaker:
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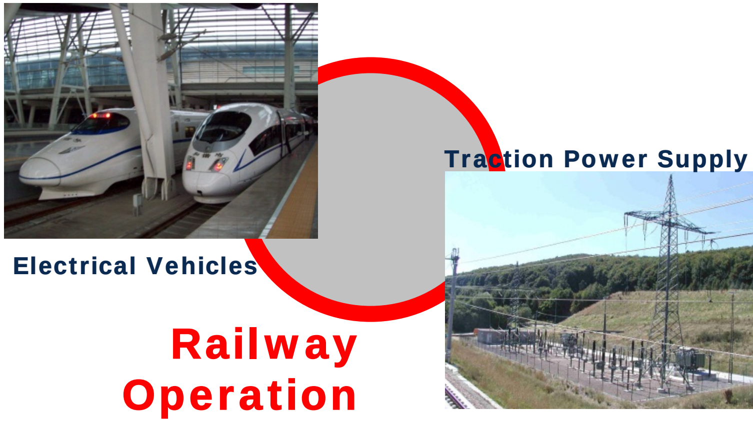
TROLLEY Summer University
25.10.2012
Leipzig, Germany

Structure

0 Chair for Electric Railways

- Sascha Giebel:
  - studied transport engineering at TU Dresden (2005 - 2011)
  - specialization: Planning and Operating of Electrical Transportation Systems
  - since 2011: Ph.D. student at the Chair for Electric Railways (Prof. Stephan)

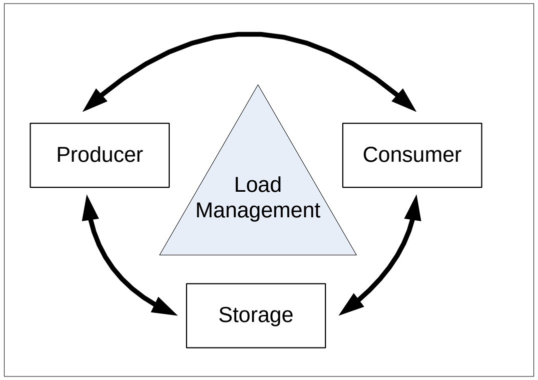


- Scientific fields of the chair:

  - **energy generation/transmission**
  - **energy distribution/supply**
  - **electric vehicle**
  - **return current, em influence**
  - **vehicle and system operation**

- systems laboratory for railway vehicles
- railway operation simulation programs

1 Introduction



Characteristics of Electric Vehicles:

- key benefits:
  - high efficiency of electric propulsion system ($\eta_{propulsion}$ = 0,8…0,9)
  - bidirectional load flow (recuperation)
- challenge:
  - public opinion: (individual) E-Cars are green!
    → how is it possible for the public electric vehicles to maintain their good reputation?!
  - energy source is not on board!
    - η_{total} = 0,25…0,70
  - maximum comfort vs. “green energy” (e.g. HVAC, spots and ambient lighting)

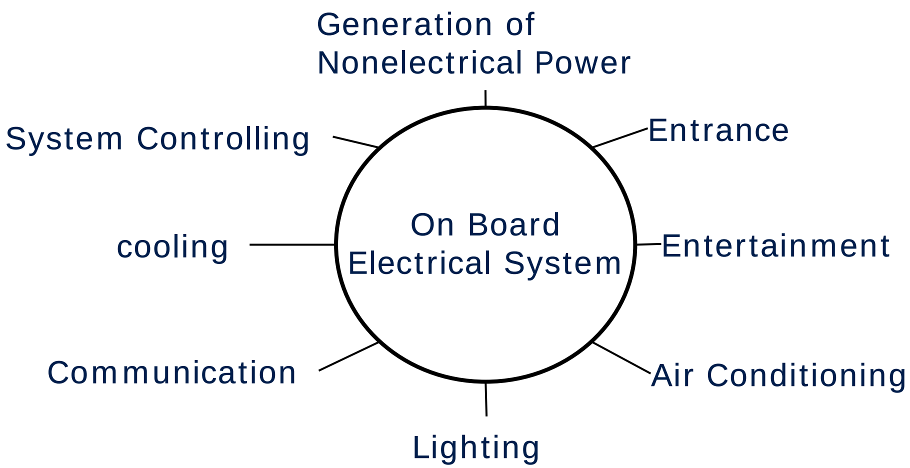
→intelligent power and load management between producer, consumer and storage

2 Classification of On-Board Consumers

2.1 Definition “On-Board Electrical System”

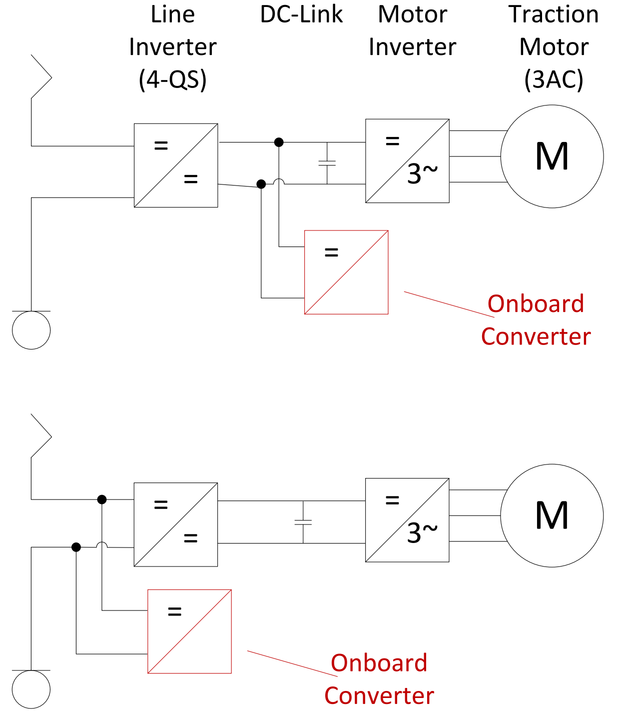
The on-board electrical system is the part of a vehicle, that contains all electrical loads which are not directly part of the propulsion system

Some known functions:



Propulsion System’s Structure

(e.g. DC 750 V)



2.2 Characteristics On-Board Electrical Systems

On-board electrical systems for electric railways

- railway: $P_{\text{board, install}}$ = 8 ... 12% $P_{\text{total, install}}$
- Many different consumer with normative guidelines, but few standards for the system architecture (e.g. EN 50534)
- voltage (EN 50333; EN 50155; EN 50535)
  - 3AC:
    - frequency variable
    - 50 Hz: 380V, 400V
    - 60 Hz: 440V, 480V
    - up to $0{,}7U_N \leq U_N \leq 1{,}1U_N$
  - DC:
    - 24V, 48V, 72V, 96V, 110V
    - up to $0{,}7U_N \leq U_N \leq 1{,}25U_N$

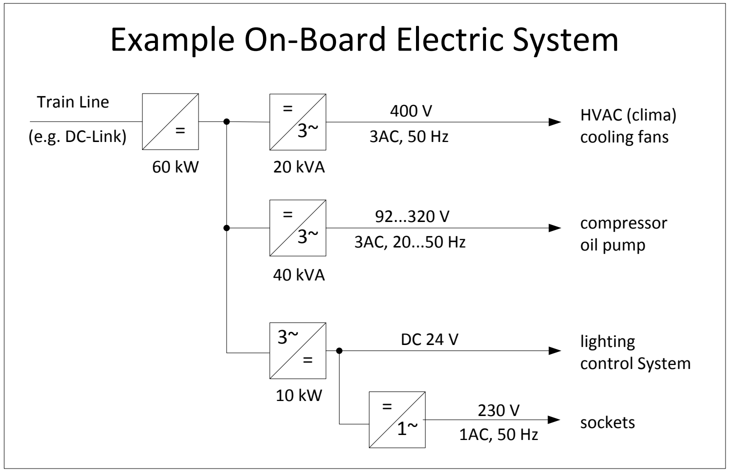
→ Best classification: functional groups

B.2 Typical ratings of auxiliary power converters and battery chargers

Type	Vehicle type	Typical Power rating
ACU.1:	Coaches	50 kVA to 80 kVA
ACU.2:	Motor Cars	300 kVA to 400 kVA
ACU.3:	Power Heads	700 kVA

Type	Vehicle type	Typical Power rating
BC.1:	Coaches	5 kW to 20 kW
BC.2:	Locomotives, power cars or power heads	10 kW to 60 kW

Source: EN50535



2.3 Classification for public transport systems (e.g. high speed train)

on-board electrical system

	power supply loads	**auxiliary loads**	**operational required loads**	**comfort loads**
FUNCTION	*generation, distribution and supply of the energy in on-board electrical systems*	*allow the reliable operation of the propulsion under all defined conditions*	*given by operative, judicial or normative rules*	*power of attraction for passengers*
LOADS	• static inverter, battery charger • wires • switches, fuses, ...	• cooling fans • compressor • pumps • sanding devices • controlling devices	• safety systems • communication systems • electrical lighting (inside/ outside) • fire alarm system • doorway (doors) • oiling devices (flange oilers)* • HVAC* • plumbing unit*	• sockets • entertainment systems • kitchen loads

***) depends on operation focus**

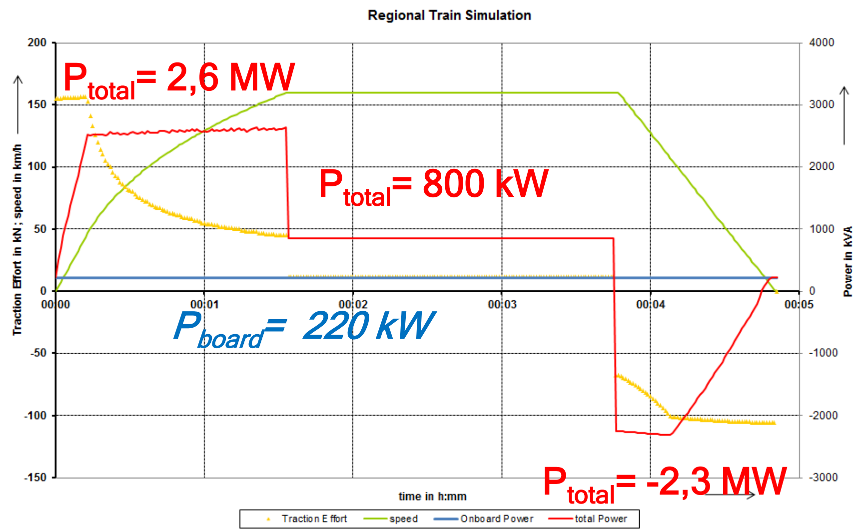
3 Influence of the On-Board Electrical System

When is the on-board electrical system interesting?

- state-of-the-art: constant energy consumption for on-board electrical systems in railway simulation programs (e.g. OpenTrack)

Regional Train Simulation (Station A – Station B):

- Accelaration: $P_{board} \approx 8\% \, P_{total}$
- Cruising speed: $P_{board} \approx 31\% \, P_{total}$
- (coasting down: $P_{board} \approx 100\% \, P_{total}$)
- Brake: $P_{board} \approx 10\% \, P_{total}$
- Station: $P_{board} \approx 100\% \, P_{total}$
- Standby: $P_{board} \approx 100\% \, P_{total}$

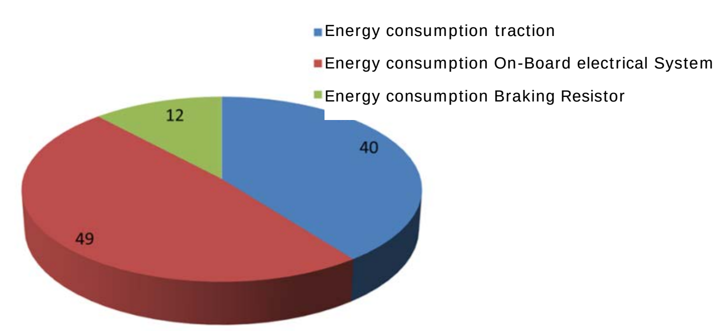


→ percentage in energy consumption?

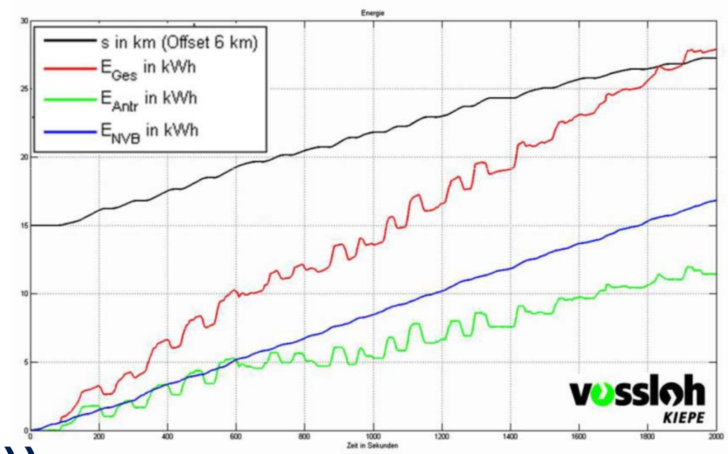
Comparison of 3 Types of Railway Operation

- high speed train (1,5 h):
  - P_{total} = 8000kW; E = 11000 kWh
  - P_{board} = 960 kW; E = 1440 kWh
  - P_{rel} = 12 %; E_{rel} = 13,1 %
- regional train (0,5 h)
  - P_{total} = 2000kW; E = 330 kWh
  - P_{board} = 200 kW; E = 100 kWh
  - P_{rel} = 10 %; E_{rel} = 30,3 %
- tram (1 h):
  - P_{total} = 510 kW; E = 53,5 kWh
  - P_{board} = 40 kW; E = 20 kWh
  - P_{rel} = 7 %; E_{rel} = 37,5 %
  - **measurements:**
    - **E_{rel} = 49 % (40 days without HVAC),**
    - **(E_{rel} = 60 % (30 minutes with HVAC))**

→ Influence Depends on Operation Focus!



748 hours of operation (40 days)
source: G. Dürrschmidt; presentation on 23. VWT



Source: U.v.Stockhausen: Bordnetzkonzepte für Nahverkehrsfahrzeuge U-Bahnen und Stadtbahnen; Workshop Bordnetzmanagement 2011

4 Strategies to improve the energy efficency

4.1 General Strategies

View from System and Control Level (examples):

- decentralized supply
  - individual demand for every unit or
  - power on according to real demand in subnetworks
- higher DC-voltage-level
  - 24V @ P_{DC}=9 kW → I_{DC}= 406 A
  - $P_{loss} \sim I^2R \rightarrow P_{loss,24V} \geq 4 * P_{loss,48V}$
  - depends on transmission power, cables,...
  - Example with same conductor cross section

	24 V	28 V	48 V
P_{load}	9 kW	9 kW	9 kW
I	406 A	340 A	191 A
P_{loss}	756 W	530 W	167 W
$P_{loss,X}$ / $P_{loss,24}$	1	0,7	0,22

- intelligent load management
  - using braking power for the on-board electrical system
  - enlarge set point adjustment for comfort loads (e.g. temperature)
  - reduce voltage range (e.g. ±5%)

4.1 General Strategies

Auxiliary loads (examples):

- speed variable fans and pumps
  - $P \sim n^3$
- set control depending on need
  - fan control (on/off switch)
  - shut down unnecessary loads (e.g. oil pumps in parking position)
  - reduce heating power over night
- efficiency degree:
  - operation of traction unit in optimal working point (constant high efficiency degree)
  - get a higher efficiency degree for traction units in construction (less auxiliary loads)

4.2 Example HVAC (Heating, Ventilation, air conditioning)

Maximum permitted mean interior temperature:

	Main Line	Urban, Suburban		Driving Cab	
		Cat. A	Cat. B	Cat. A	Cat. B
Summer I	27°C	30°C	32°C	27°C	30°C
Summer II	27°C	30°C	33°C	26°C	28°C
Summer III	25.25°C	26°C	29°C	22°C	24°C
Winter I, II, III	22°C	15°C	10°C	18°C	18°C

- main functions:
  - fresh air supply und exhaust air supply
  - heating and cooling
  - dehumidification
- characteristics:
  - largest consumer in on board electrical systems
  - often largest energy consumption in winter
- requirements:
  - EN 13129 (main line rolling stock),
  - EN 14750 (urban and suburban rolling stock),
  - EN 14813 (driving cab)
  - e.g. maximum permitted mean interior temperature

    → **is this necessary during operation?**

4.2 Example HVAC (Heating, Ventilation, air conditioning)

Target: Reduce Energy Consumption while maintaining the Comfort

Energy savings referenced to a passenger coach with 80 MWh*:

- Improvement Strategies:
  - Use fresh air for cooling → (3...8%)
  - heat pumps → (25...45%)
  - heat recovery → (20...35%)
  - demand-controlled fresh air supply → (20...40%)
  - optimize the thermal insulation
  - enlarge set point adjustment
  - load control for compressor
  - adjust door opening time
  - ...

***) over 6120h; Source: L. Boeck u.a.: Betrachtung zum Jahresenergieverbrauch von Klimaanlagen – Möglichkeiten der Reduzierung; Workshop Bordnetzmanagement Kaiserslautern; 2011**

→ **efficiency improvement results depend on vehicle, track, climate, operation focus,...**

5 Conclusion

- state-of-the-art: many different network standards and many different consumer
  - classification in functional groups allows a design comparison of on-board electrical systems

- influence of on-board electrical systems:
  - depend on operation focus
  - high percentage in urban and suburban rolling stock

- efficiency improvement of the on-board electrical system:
  - different options in system level, functional groups and unit level
  - check the necessary of standard set points in operation
  - results depend on different conditions (vehicle configuration, track, climate,…)

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Further interesting Fields:

- variety of goods
    - types of network configuration in voltage, function and size
    - electrical vehicles with similar electrical structures

      → **see the bigger picture!**

- Future strategies for the development of efficiency strategies:
    - analyzing the consumers: know/measure power, function and runtime of the electrical consumers
    - investigation of the interaction between the consumers

      → **System approach!**

Thank you for your attention.
Do you have any questions?

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