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Panel 4 – Electric AC High Speed Services

Medium-Frequency Traction Transformer – Outcome of Railenergy

Jan Weigel, Siemens AG

Agenda

- Basic Concept
- Overview of Components
- Investigation of MF-DC/DC Converter
- Energy Efficiency
- Application Aspects
- Summary

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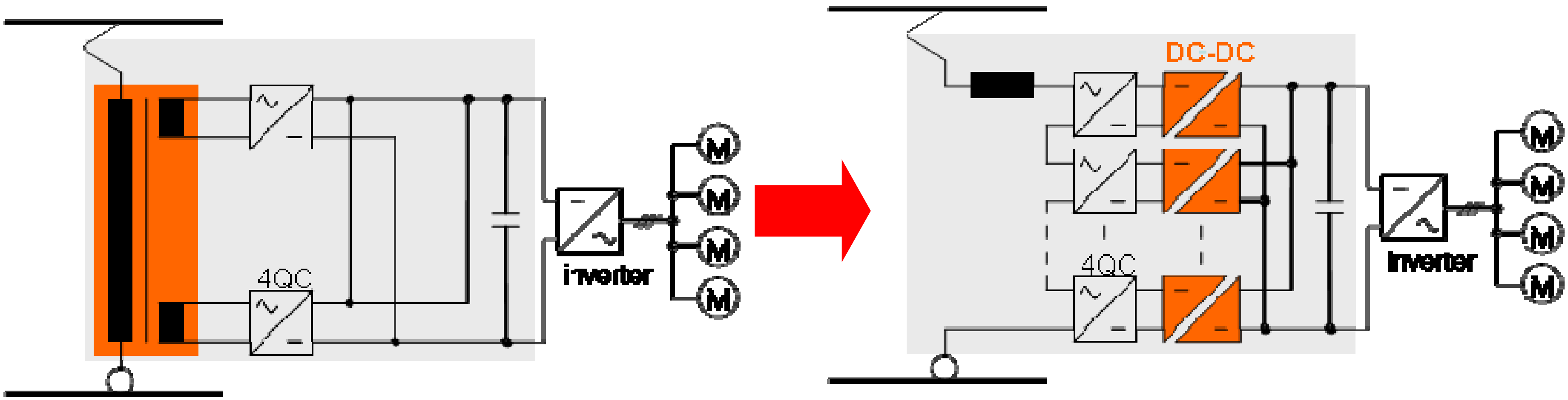
Basic Concept

Conventional | Medium frequency technology



Transformer efficiency is negatively influenced by

- Weight constraints
- Space constraints

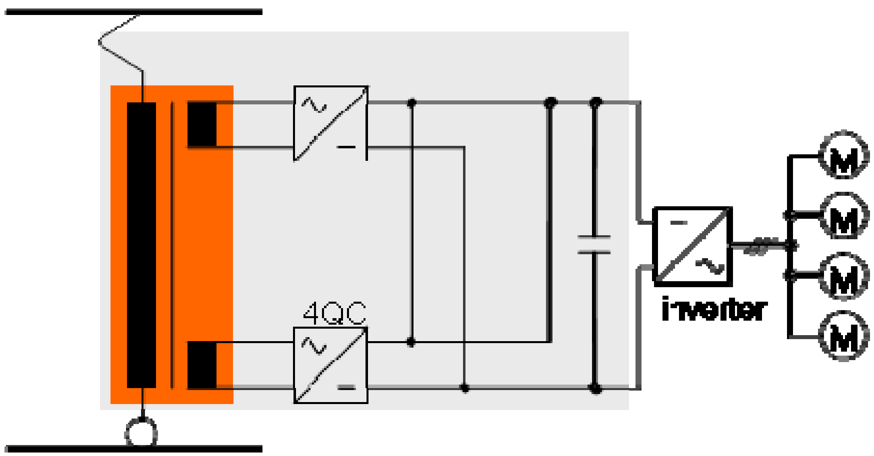
However – it still remains heavy and large

Conventional transformer substituted by HV converter comprising

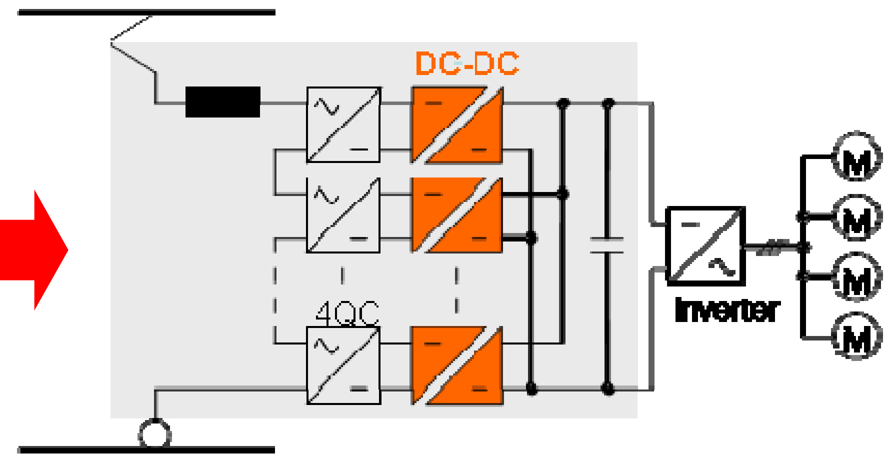
- Line choke
- series connected converters
- MF DC/DC converters (high power density)

Basic Concept

Conventional



Medium frequency technology



Transformer efficiency is negatively influenced by

- Weight constraints
- Space constraints

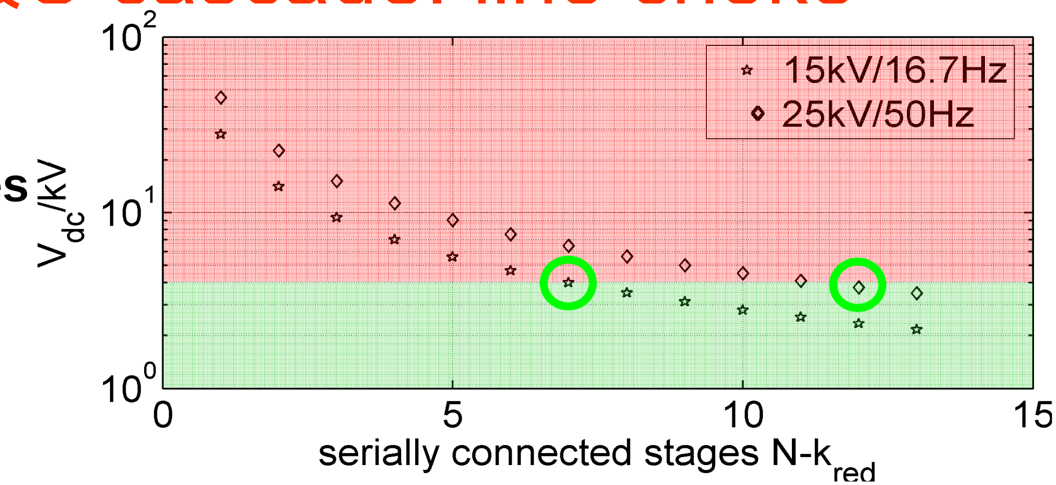
However – it still remains heavy and large

Conventional transformer substituted by HV converter comprising

Advantages

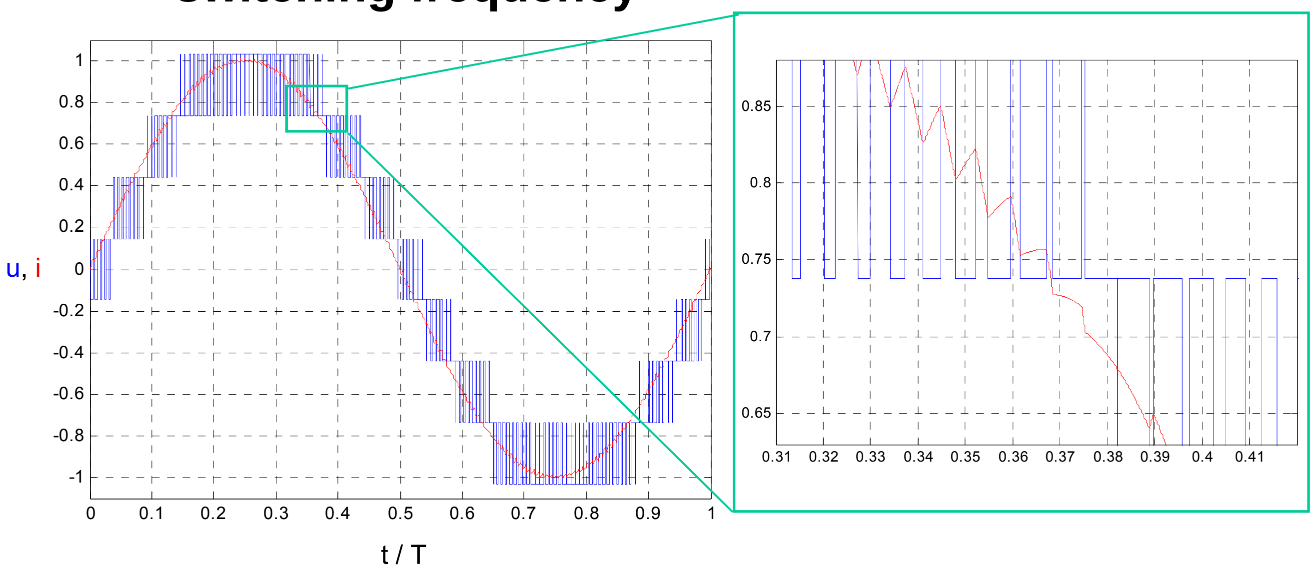
- **Efficiency↑**
- **Weight↓**
- **Scalable platform**
- **Flexible installation**

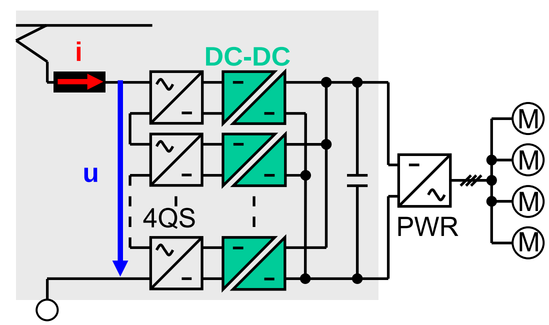
Components – 4QC cascade. line choke



4QC cascade

- **# 15kV/25kV →min. 7/12 stages**
- **→3.6kV rated dc voltage**
- **f_S → low as conventional, however, resulting in a high switching frequency**





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Components – 4QC cascade, line choke

4QC cascade

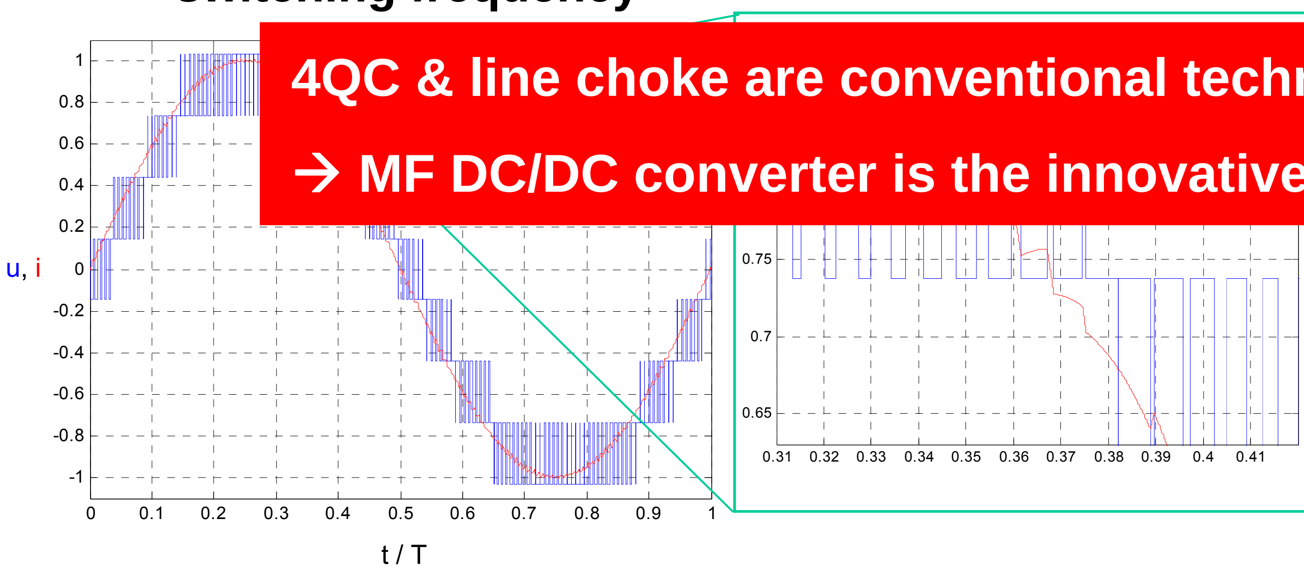
- # 15kV/25kV → min. 7/12 stages
- → 3.6kV rated dc voltage
- f_S → low as conventional, however, resulting in a high switching frequency

Line choke

- Line compatibility
- surges

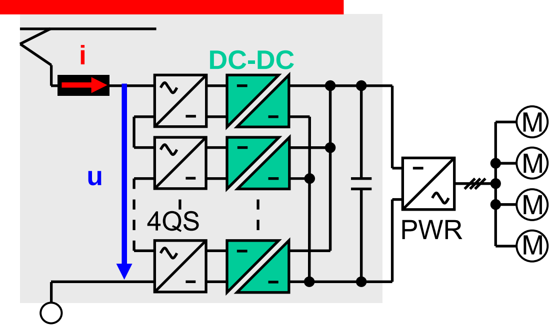
} → passive impedance

- Insulation as for conv. transformer



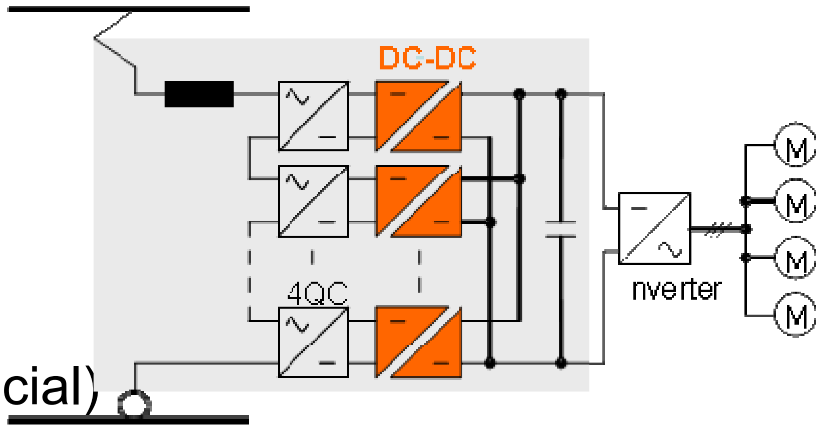
4QC & line choke are conventional technology

→ MF DC/DC converter is the innovative component!



Components – MF DC/DC converter

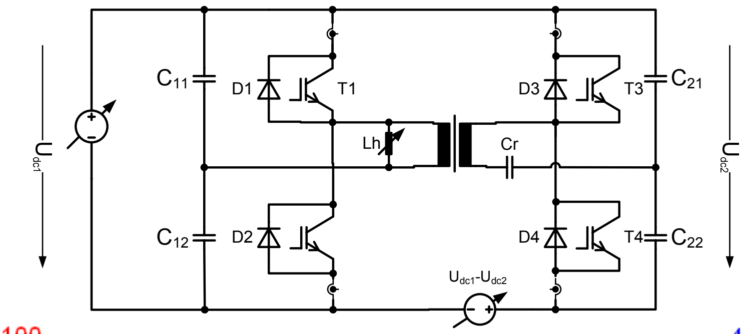
- Dual active bridge → bidirectional power flow (drive & energy recovery)
- Pulsating power throughput (harmonic absorber on motor side)
- High power density / small design
  - f_S↑ → transformer weight/size↓
  - High performance cooling
  - Low effort for control
- Series resonant dc/dc-converter (beneficial) → low effort for control of power flow and voltage

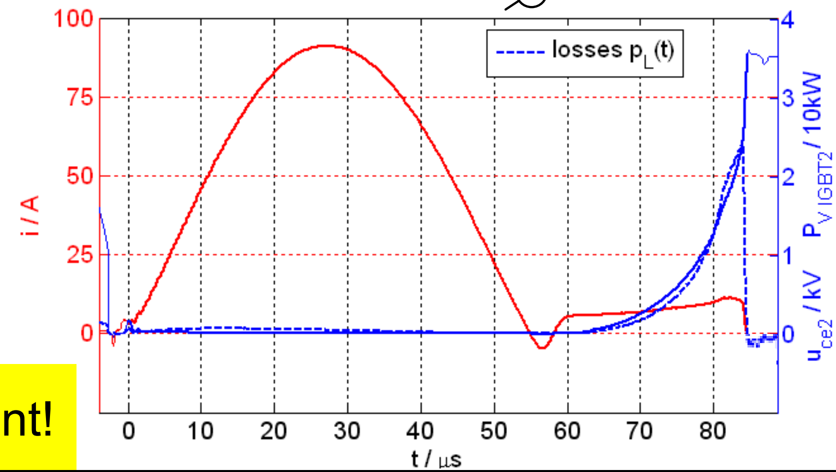


- Suitable switching frequency f_S for HV IGBTs in soft switched mode?
- Potential of future generations of power semiconductors ?

Lab prototype testing

- Prototype setup in back-to-back mode
  - Adjustment of…
    - Pulse pattern
    - Magnetizing inductance
    - Voltage difference
  - Target
    - Suitable switching frequency @ optimized operation
    - Suitable utilization and efficiency



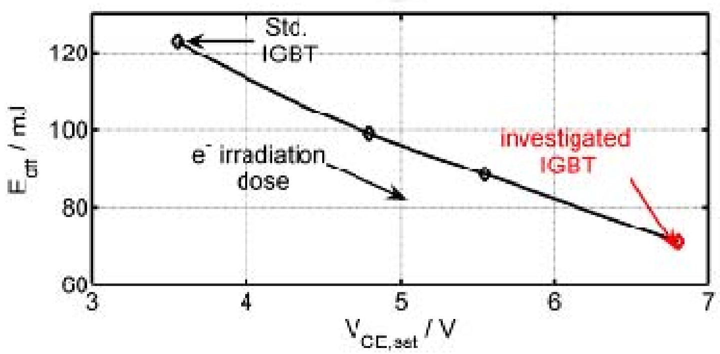


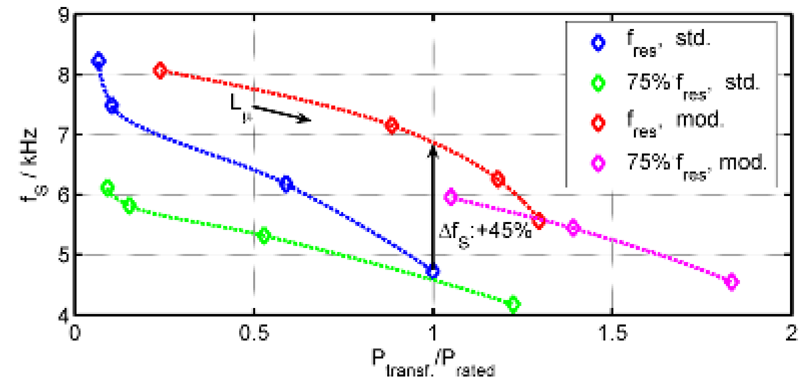
Important for f_S ↑→ appropriate magnetizing current!

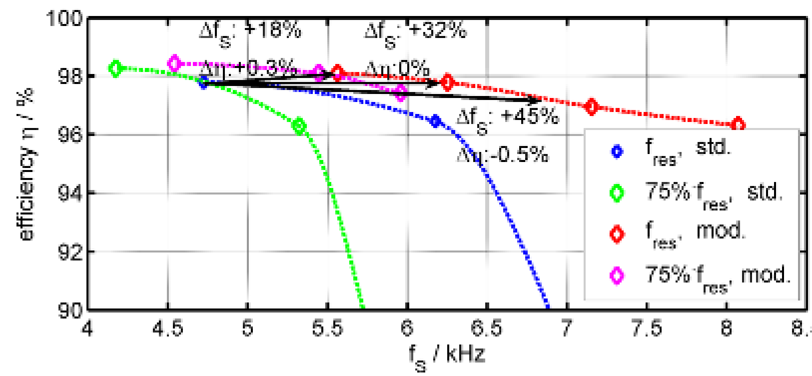
- Suitable switching frequency f_S for HV IGBTs in soft switched mode?
- Potential of future generations of power semiconductors ?

Standard ↔ modified IGBTs

- e^- irradiation → shift trade-off between switching and conduction loss
- Comparison between latest std. and modified IGBTs







- Suitable switching frequency f_S for HV IGBTs in soft switched mode?
- Potential of future generations of power semiconductors ?

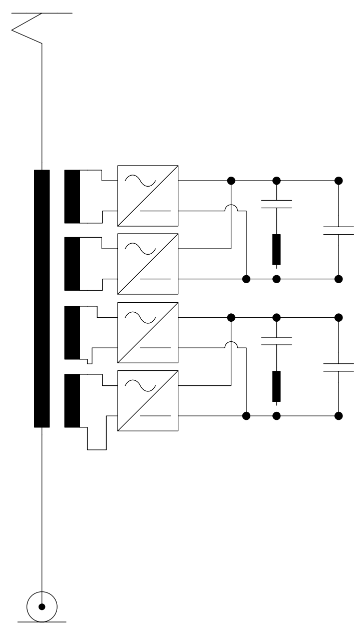
Components – cooling system

- Pumps (oil, water)
- Fans (liquid→air heat exchangers)

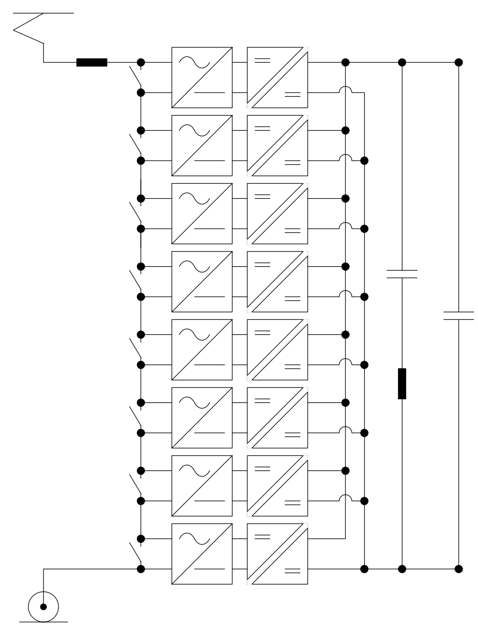
Component	Auxiliary power	
	Conv. techn.	MF- techn.
Oil pump	100%	20%
Fan for oil/air heat exchanger	100%	0%
Water pump	100%	198%
Fan for water/air heat exchanger	100%	129%
Difference between the overall auxiliary power (only cooling, w/o AC and other auxiliary equipment)	100%	103%

Availability: conventional/MF technology

- Redundancy implemented due to voltage margin required for any defect in the power electronics
- **Comp. : Conventional** **MF transformer**



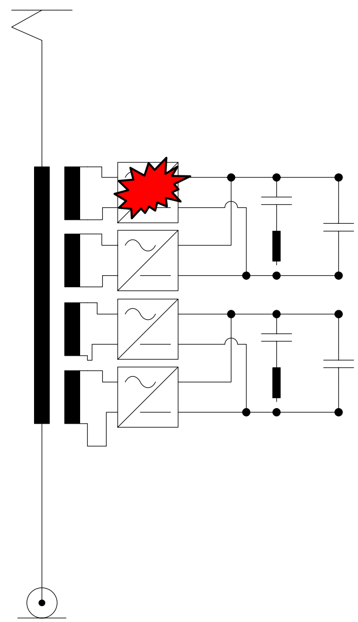
100% $P_{traction}$

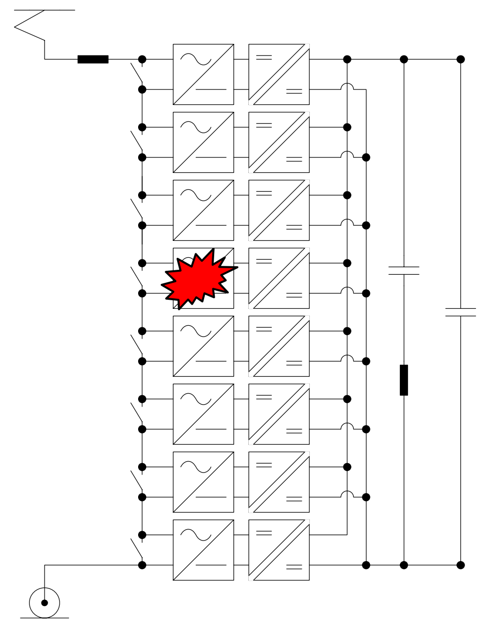


100% $P_{traction}$ (15/25kV)

Availability: conventional/MF technology

- **Redundancy implemented due to voltage margin required for any defect in the power electronics**
- **Comp. : Conventional MF transformer**





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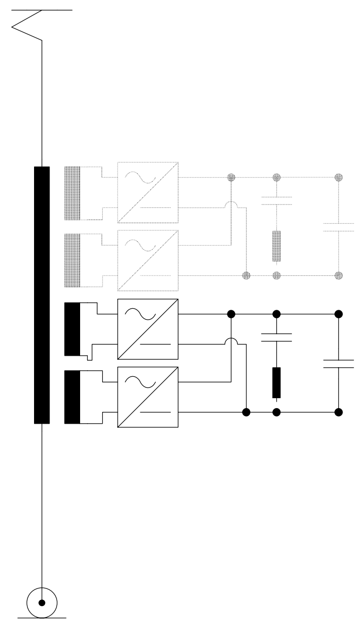
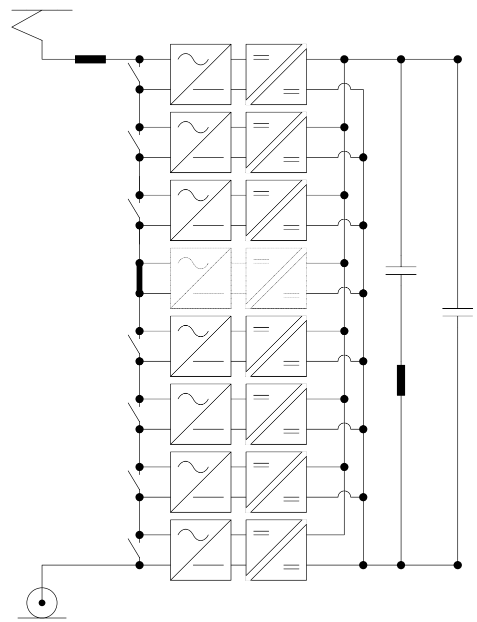


50% **P**$_{traction}$



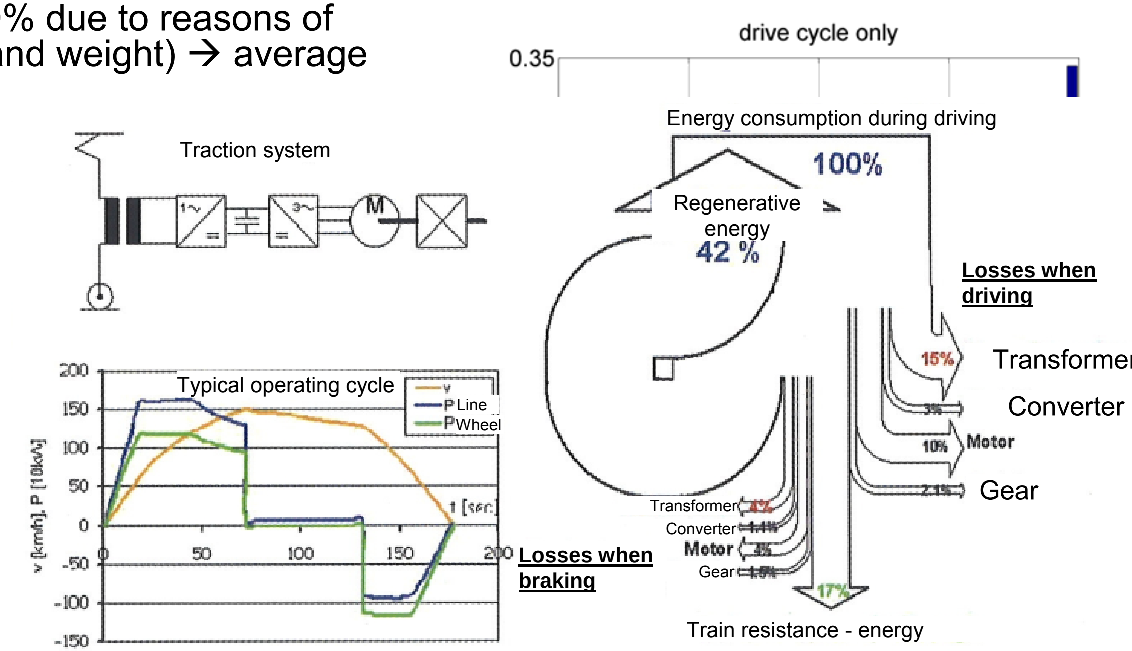
87.5%/92% P$_{traction}$ **(15/25kV)**

Promising applications

EE potential of MF- technology by application

[Source: *]

- Commuter
  - Low rated efficiency
  - High overload (160% due to reasons of installation space and weight) → average efficiency↓



Medium-Frequency Traction Transformer

[Source: *]

* Moderne Drehstromantriebstechnik – Stand und Perspektiven, ZEVrail Glasers Annalen

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Promising applications

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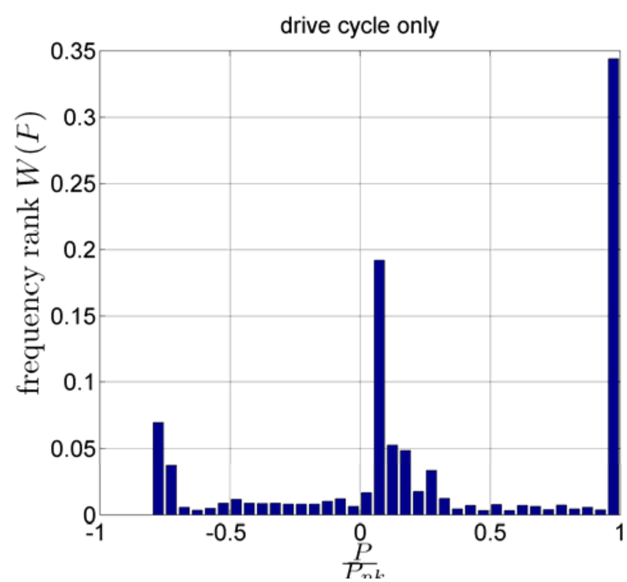
- High speed trains
  - Efficiency restricted by mass and size requirements
  - Mostly close to max. power



Medium-Frequency Traction Transformer

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Promising applications

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- Commuter → ☺
  - Low rated efficiency
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[Source: *]

- High speed trains → ☺
  - Efficiency restricted by mass and size requirements
  - Mostly close to max. power

[Source: *]

- Locos → ☹
  - Comp. high rated efficiency
  - High percentage of partial load → efficiency↑

* Moderne Drehstromantriebstechnik – Stand und Perspektiven, ZEVrail Glasers Annalen

[Source: *]

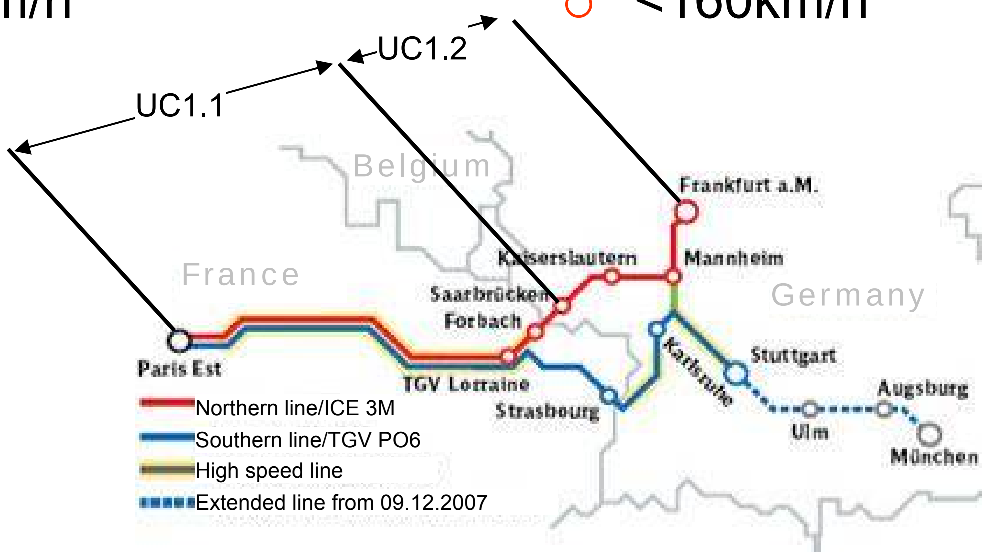
Energy efficiency: Use case 1.1/1.2

UC1.1:

- Saarbrücken→ Paris
- AC25kV/50Hz
- Cruising mode
- Up to 300km/h

UC1.2:

- Frankfurt a. M. → Saarbrücken
- AC15kV/16.7Hz
- All-out-running mode
- <160km/h



Source: www, DB

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Energy efficiency: Use case 1.1/1.2

Results

Operation Mode Only				
ID	Demonstration Scenes	Technologies	Driving mode	Relative Energy Consumpt.(KPIx)
				%
1	DS 1 UC 1.1 (Pass)	Baseline Technology	Cruising	100%
7		MF Technology (WP 5.3)	Cruising	97.9%
1	DS 1 UC 1.2 (Pass)	Baseline Technology	All-out running	100%
5		MF Technology (WP 5.3)	All-out running	95.5
6		Combined New Technology: Reduced Line Impedance (WP 3.3) & MF Technology (WP 5.3)	All-out running	92.1%

-2.1%
-4.5%

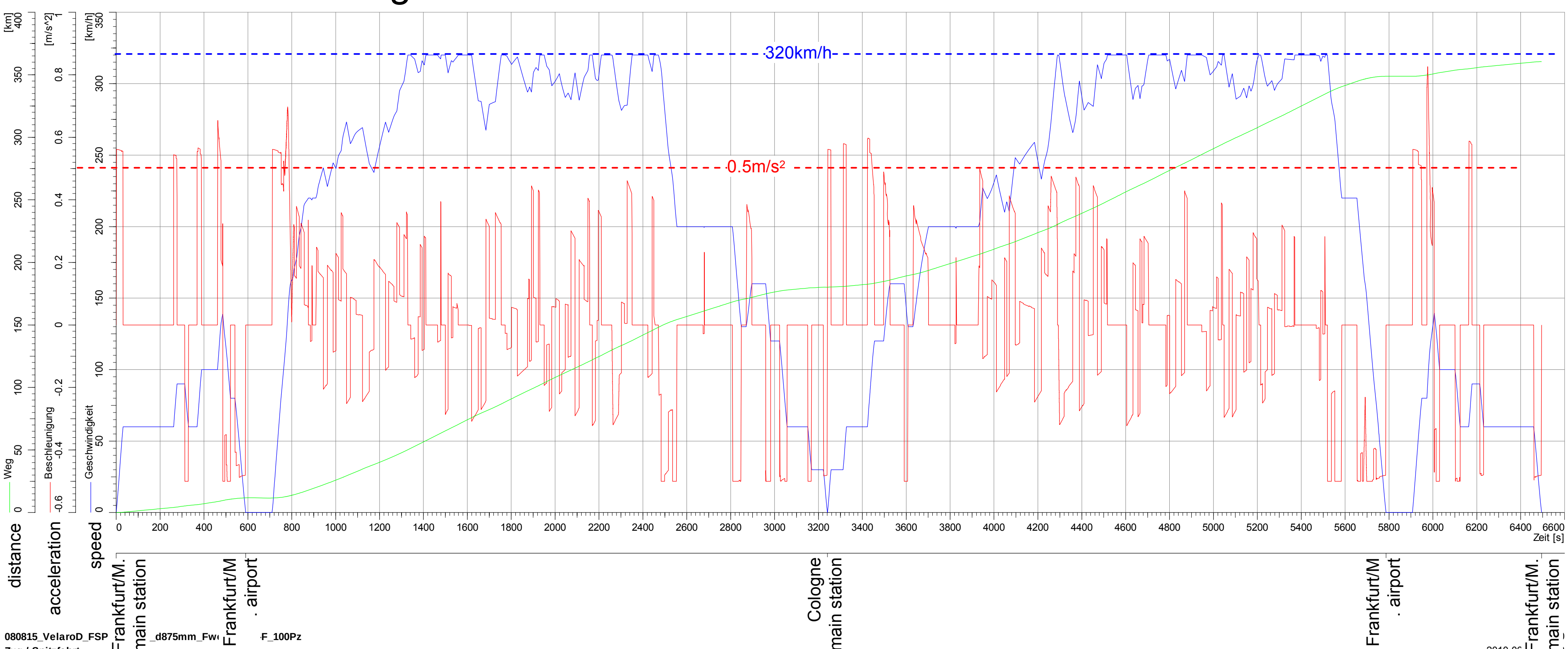
Operation and parking mode				
1	DS 1 UC 1.1 (Pass)	Baseline Technology	Cruising	100%
7		New Technology: Medium Frequency Transformer(WP 5.3)	Cruising	98%
1	DS 1 UC 1.2 (Pass)	Baseline Technology	All-out running	100%
5		MF Technology (WP 5.3)	All-out running	95.8%
6		Combined New Technology: Reduced Line Impedance (WP 3.3) & MF Technology (WP 5.3)	All-out running	92.4%

-2.0%
-4.2%

Energy efficiency: true high-speed (AC15kV)

State-of-the-art high speed line

- Specified route Frankfurt/M. – Cologne – Frankfurt/M. (roundtrip)
- All-out-running mode



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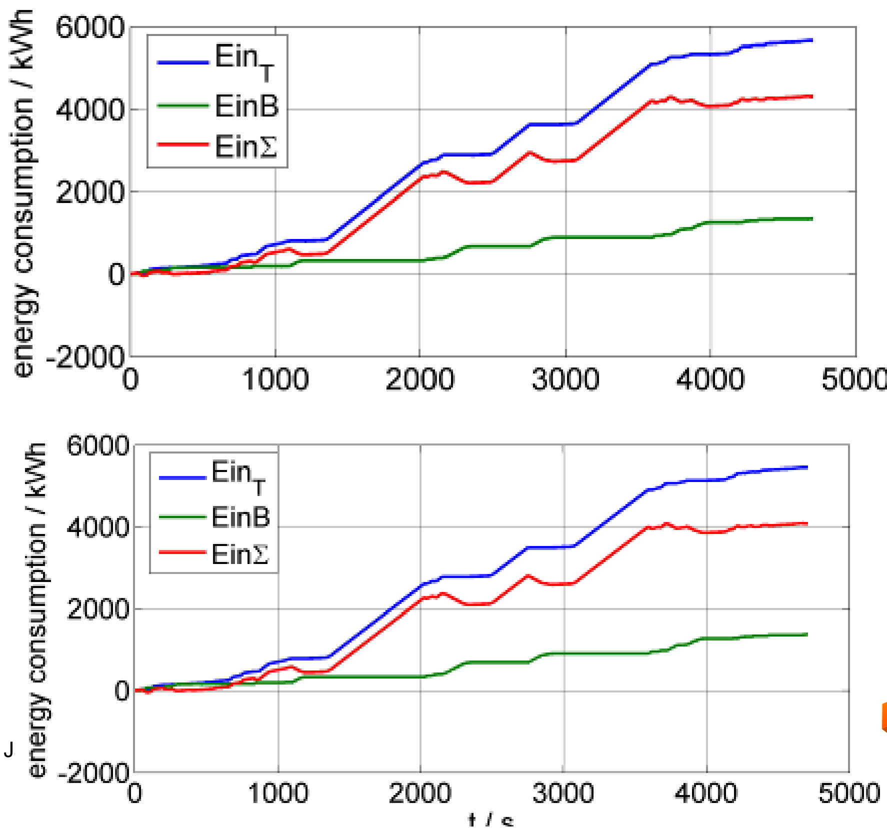
WP 5.3 – alternative 1

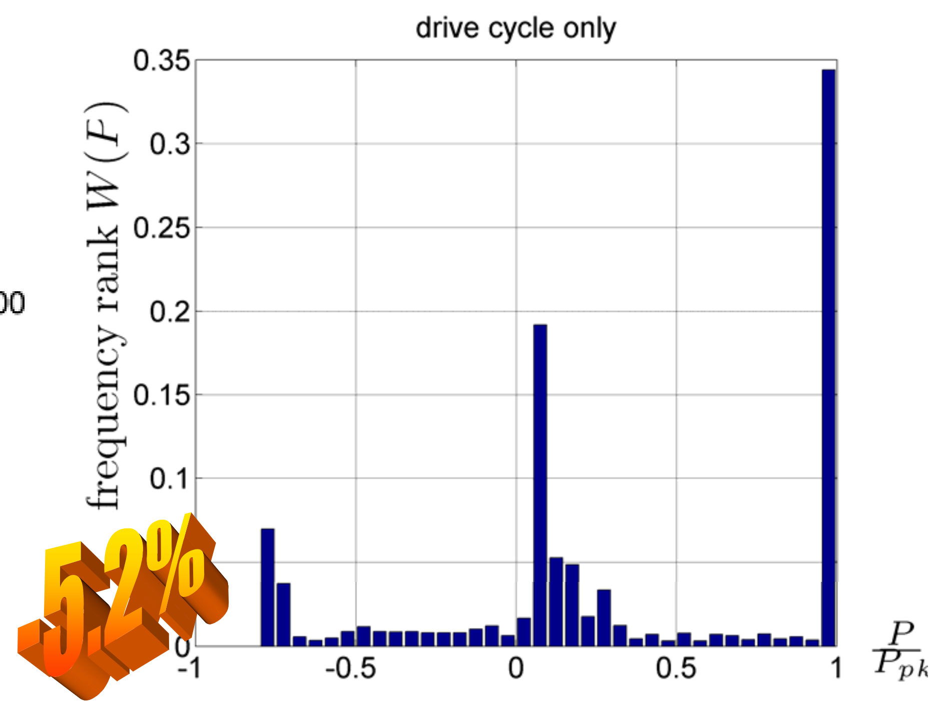
Comparison of energy consumption (drive mode only)

- Specified route Frankfurt – Cologne – Frankfurt (roundtrip)
- All-out-running mode

conventional

MF-technology





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Application aspects

MF transformer technology benefits from

- High percentage of the operating time is at high power
- Highly utilized conventional transformer
- AC15kV, 16.7Hz
  - Heavy and bulky conv. 16.7Hz transformer (trade-off: weight ↔efficiency)
  - Only 7+1 HV submodules (redundancy)

Benefits of technology cannot be fully exploited if

- High level of energy throughput is at partial load or low load (power on during parking!)
- AC25kV, 50Hz
  - Conv. 50Hz traction transformer has attractive form factor → can have higher efficiency
  - 12+1 HV-submodules (higher input voltage)

→ high speed trains are very attractive, especially AC15kV…25kV: less
→ dual system AC15/25kV application is in between

Summary

High speed train:

Conventional AC15kV traction transformer vs. MF-transformer

- MF-transformer increases the efficiency by 3-5%
- MF-transformer saves mass (axle loads!) and can allow new vehicle concepts
- MF- technology can be provided at higher investment cost, but cost for conventional traction transformer will increase (copper and iron price)
- MF- technology reduces energy usage/costs