Modern electrical propulsion systems for rolling stock

Lausanne, September 2005
Andreas Fuchs
TS GT DP
1. Comparison of DC and AC traction machines

2. System aspects and general requirements for traction converters

3. State of the art IGBT-technology, an overview

4. The traction converter family SIBAC®
   - Modular Building Blocks
   - SITRAC® improved traction control system
   - Railway vehicles with IGBT-traction converters (examples)

5. Conclusion
Motorcar Marienfelde-Zossen

- Construction year: 1903
- Number of units: 1
- Supply voltage: AC Three phase
- Continuous power: 2.2 MW
- Top speed: 210 km/h
Comparison of DC- and AC-Traction Motor

**Traction drive of:**

**E103:**
- rated power: 1230 kW at 1520 min\(^{-1}\)
- maximum torque: 8530 Nm for 5 minutes
- maximum speed: 1600 min\(^{-1}\)
- mass (without gear): 3550 kg
- moment of inertia: 120 kg m\(^2\)

**E152:**
- rated power: 1633 kW at 2280 min\(^{-1}\)
- maximum torque: 6840 Nm constantly
- maximum speed: 4000 min\(^{-1}\)
- mass (without gear): 2800 kg
- moment of inertia: 18.4 kg m\(^2\)

**Dimensions:**

- E103: 870 mm x 1200 mm
- E152: 855 mm x 910 mm
High performance hollow shaft drive

Motor 1TB2824

- voltage = 1840 V
- current = 590 A
- rated power = 1630 kW at 1485/min
- max. torque = 10500 Nm
Traction converters have to work at various catenary voltages and have to cope with a wide output power range.

<table>
<thead>
<tr>
<th>Characteristic, Parameter</th>
<th>Typical range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Catenary voltage</td>
<td>DC 750 V ... 3000 V</td>
</tr>
<tr>
<td></td>
<td>AC 15 kV ... 25 kV</td>
</tr>
<tr>
<td>Power of the propulsion system</td>
<td>0,5 ... 2.0 (3,5) MW</td>
</tr>
<tr>
<td>Reliability</td>
<td>1000 Fit / IGBT + driver (1 Fit: 1 failure / 10⁹ h)</td>
</tr>
<tr>
<td>Failure behaviour</td>
<td>Restricted to converter module</td>
</tr>
<tr>
<td>Mechanical construction</td>
<td>Flat underfloor converter cubicle for EMU and Metro</td>
</tr>
<tr>
<td></td>
<td>Switchgear cubicle or locomotives</td>
</tr>
</tbody>
</table>
Chopperless multi system converter with 6,5 kV IGBTs

Diagram showing the circuit with labels for DC, L_f, AC, 4QC, DC-Link, PWR, U_d, C_d, 15kV, 16 2/3Hz, 25kV, 50Hz, and 3M.
IGBTs with different blocking voltages are offered by several semiconductor suppliers in a housing with the same footprint.

Module design of a 1.7 kV – 1200 A IGBT

Module design of a 6.5 kV – 600 A IGBT
Typical variation of the base plate temperature during the lifetime of an IGBT in a traction converter (EMU operation)

Power semiconductor devices, due to the operation of railway vehicles, have to withstand a high number of load cycles during lifetime.
Thermal cycling capability of the base plate and the bondwires (traction IGBT)

Introduced technologies:
- Al SiC-base plate
- Polyimid passivation on the chip surface
The traction converter family SIBAC®

Compact inverter

- Up to 3 kV line voltage
- Air cooled or water cooled

IGBT Building Block SIBAC® BB

- Up to 3 kV line voltage
- Air cooled or water cooled
Typical output power limits of SIBAC® IGBT traction converters

- **BB - forced air** (BB 750 F, BB 1500 F)
- **BB - water** (BB 1500 W, BB 3000 W)
- **CC - forced air** (CC 750 F, CC 1500 F)
- **CC - water** (CC 1500 W, CC 3000 W)

*Note: The graph shows the power capability of IGBT converter modules.*
Overview SITRAC: Siemens Traction Control

Requirements of vehicle

<table>
<thead>
<tr>
<th>Inverter</th>
<th>Motor</th>
<th>Functions</th>
</tr>
</thead>
</table>

Project-specific

STDSG / ZR

I/O

Parameters

ICU / Application-SW

Power stage

General

Inverter functions (e.g. protection)

Control functions

General drive functions

SITRAC functions
SITRAC PWR block diagram of the control structure without speed encoder

- Torque control
- Rotor-flux control
- Speed and parameter adaption
- Control of stator mesh = OFT (Optimal flux tracking)
- Inverse inverter model
- Motor model
- Estimated parameters
- Estimated speed
- Gate signals
- Inverter
- Motor

Symbols:
- \( T \): Torque
- \( \omega \): Angular speed
- \( \psi \): Flux
- \( I \): Current
- \( \Omega \): Angular frequency
- \( \psi_{r,ref} \): Rotor flux reference
- \( \psi_{s,ref} \): Stator flux reference
- \( \psi_{r} \): Rotor flux
- \( \psi_{s} \): Stator flux
- \( I_{s,ref} \): Stator current reference
- \( I_{s,mod} \): Modulated stator current
- \( V \): Voltage

Copyright © Siemens AG 2005. All Rights Reserved.
Sitrac – Hardware
Inverter control unit for the compact inverter
Electric Multiple Unit RENFE TREN 2000

Supply system: DC 3 kV
Train configuration: 2 ... 5 sections, 50 % ... 60 % driven axles
Rated power: 0.6 MW / converter, 1C2M
Traction converter: IGBT compact converter CC 3000 W
Electric Multiple Unit RENFE TREN 2000

Compact inverter SIBAC®
EuroSprinter Class 189 four-system locomotive for German Rail
Chopperless multi system converter with 6,5 kV IGBTs

EuroSprinter Class 189 four-system locomotive for German Rail
SIBAC® Building Block

EuroSprinter Class 189 four-system locomotive for German Rail
Traction converter of the class 189 locomotive