Visions for Power Electronics in Automotive Applications

Dr. Bernd Eckardt

Fraunhofer-Institut für Integrierte Systeme und Bauelementetechnologie, Schottkystrasse 10 ● 91058 Erlangen ● Tel. 09131/761-139, Fax -312
www.iisb.fraunhofer.de
Power Electronic Systems for Next Generation Vehicles

Fuel Cell Vehicles

Plug-in Hybrids & Full Electric Vehicles

Hybrid Vehicles (HEV)

High Power Loads

- x-by-wire
- active suspension
- electric valves
- air-con compressor

Electrical Energy Storage
Conventional system architecture ▪ Central power-electronic unit

Problems
- High costs resulting from the required high-voltage (copper-) cables and connectors\(^1\)
- Additional weight (casings, connectors etc.)
- Additional effort for safety, reliability and EMC

\(^1\) In the example 11 HV-cables und 22 connectors
Visionary system architecutre • **System integrated power-electronics**

**Advantages**

- Reduced number of shielded HV-cables and HV-connectors\(^1\)
- **No external AC-cables** (only DC-connections)!
- Significant reduction of costs and additional weight!

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\(^1\) In the example 2 HV-cables and 6 connectors
Intelligent e-Drives

Drives with system integrated inverter(s)

**Single wheel axle drive**
- for hybrid cars and small electric vehicles
  - (2x 20 kW, 2x 500 Nm)

**Single wheel axle drive**
- for light-trucks and buses
  - (2x 80 kW, 2x 2.000 Nm)

**Wheel hub motor**

Projects of „Fraunhofer Systemforschung Elektromobilität“ – funded by BMBF
Converter integration in wheel hub motor

Performance data
- eMotor power: 30 (60) kW
- PM outrunner motor
- DC-link voltage: max. 400 V
- Available space: ~ 2 liters
- Converter with 6 phases
- Integrated water-cooling

Challenges
- High mechanical shock- and vibration-loads
- Reliable sealing

A project of the 'Fraunhofer Systemforschung Elektromobilität'
Hybrid axle-drive-unit (2x20 kW)

Attached double-converter

Technical data
- Two independent asynchronous motors
- Two planetary reduction gears (6:1)
- Per wheel: 20 kW, 500 Nm
- Integrated double-converter with 2x 45 kVA
- FOC with single-wheel torque control
- Enhanced efficiency model

Innovations
- Modular double converter
- Direct cooled DCB/DAB substrates (ECPE/FhG WO 2007/090664)
- Cooling concept, vehicle integration

1) Including gear losses and thermal network
Non Isolating Power Train DC/DC Converters

Vision: Power Density of 250 kW/dm³
Fraunhofer Institute of Integrated Systems and Device Technology

Records in Power Density of bidirectional DC/DC Converters

- **2004**: 70 kW mit 5 kW/dm³ @ 96%
- **2007**: 100 kW mit 25 kW/dm³ @ 96-97%
- **2010**: „MultiPort“ Converter 40 kW/dm³ @ 98%
- **2013**: „GaN“ Converter 100 kW/dm³ @ 99%
- **2014**: 143 kW/dm³

2014

200 kW
DC/DC-Converter
Volume: 1.4 l
Power Density: 143 kW/l
Comparison of DC/DC converter solutions using different PS\textsuperscript{1) } technologies

**Bipolar / Unipolar** • Si-IGBT / SiC-Diode (600 V)

- Output power: \textbf{100 kW} (max.)
- Switching frequency: 100 kHz
- Efficiency: \textbf{97,5\%} (max.)
- Topology: Multiphase Buck/Boost
- Power density: \textbf{25 kW/Liter}

\begin{center}
\begin{tikzpicture}
  \begin{axis}[
    xlabel=Output Current $I_{LV}$ [A],
    ylabel=Efficiency [%],
    xmin=0, xmax=200,
    ymin=85, ymax=100,
    xtick={0,40,80,120,160,200},
    ytick={85,90,95,100},
    \addplot+[mark=diamond*] table[x=Input Current, y=Efficiency, col sep=comma] {data.csv};
  \end{axis}
\end{tikzpicture}
\end{center}

\textbf{Buck mode:} $V_{HV} = 450$ V, $V_{LV} = 300$ V

\textbf{w/o phase removal}

\textbf{with phase removal}

- Output power: 100 kW (max.)
- Switching frequency: 100 kHz
- Efficiency: 97,5\% (max.)
- Topology: Multiphase Buck/Boost
- Power density: 25 kW/Liter

\textsuperscript{1) } Power Semiconductor
Multiport DC/DC Converter

120 kW Buck/Boost Converter

- Six buck/boost channels (each 20 kW)
- Each channel can be configured as
  - power source or load,
  - current or voltage controlled
- Fully digital control, CAN interface
- Input/output voltage up to 450 V
- Water-cooled
- Volume: 3 liters

- Switching frequency: 200 kHz
- Efficiency: 98.75% (max.)
- Power density: 40 kW/liter
- Si MOSFET and SiC diodes
Ultra-fast Switching with Modern Power Semiconductors

RF-like Device and System Designs are Mandatory

Key success factors are

- minimization of parasitics
- capacitors with exceptional high current rating
- effective cooling of active and passive devices
- high robustness (thermo/mechanical)
Isolating DC/DC Converters

Vision: Compact and Highly Efficient
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- 5 kW DC/DC converter

Copper busbar in case of serial connected inputs

**Technical Data**

<table>
<thead>
<tr>
<th></th>
<th>Serial</th>
<th>Parallel</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Converter Rating</strong></td>
<td>5 kW</td>
<td></td>
</tr>
<tr>
<td><strong>Input Configuration</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Input Voltage</strong></td>
<td>550 V to 800 V</td>
<td>225 V to 400 V</td>
</tr>
<tr>
<td><strong>Output Voltage</strong></td>
<td>16 V to 32 V</td>
<td></td>
</tr>
<tr>
<td><strong>Output Current</strong></td>
<td>up to 200 A</td>
<td></td>
</tr>
<tr>
<td><strong>Max. Coolant Temperature</strong></td>
<td>85 °C / 185 °F</td>
<td></td>
</tr>
<tr>
<td><strong>Switching Frequency</strong></td>
<td>100 kHz</td>
<td></td>
</tr>
<tr>
<td><strong>Dimension</strong></td>
<td>140x170x42 mm³</td>
<td></td>
</tr>
<tr>
<td><strong>Weight</strong></td>
<td>2250 g</td>
<td></td>
</tr>
<tr>
<td><strong>Power Density</strong></td>
<td>5 kW/dm³</td>
<td></td>
</tr>
<tr>
<td><strong>Efficiency</strong></td>
<td>up to 95.7 %</td>
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</tbody>
</table>
Insulating DC/DC Converters for 14/24V on-board Power Supply

2,5 kW Insulating DC/DC-Converter
- Input voltage range from 240 V to 400 V
- Output voltage range: 9 V to 16 V
- Output current: 180 A
- Volume: 250 cm³ (10 kW/cm³)
- Efficiency up to 95 %
- Fully digital control
- EMI filter chokes based on polymer bonded soft magnetics

500 W Insulating DC/DC-Converter
- For 14 V supply of electric cars during charging
- Optimized for high efficiency up to 96%
- Input voltage range from 240 V to 400 V
- Volume: 50 cm³
- Power density: 10 kW/cm³

Modern Power Converters
No limiting factors regarding the Smart Battery Approach. Neither with respect to size nor with respect to power dissipation (i.e. the thermal budget of the battery system).
Chargers

Vision: Inductive Charging is the Future
Universal On-Board Quick-Charger

**Features**

- ✔ 22 kW charging power
- ✔ Galvanic isolation
- ✔ Modular design approach
- ✔ Volume (size): 11.2 l
- ✔ Efficiency: up to 94 %
- ✔ Output voltage range: 320-450 V
- ✔ Low-ripple DC output current
- ✔ 1 to 3 phase AC input
- ✔ Suitable to Typ-A RCDs
- ✔ Supporting charging mode 2 and mode 3 according DIN EN 61851-1
- ✔ Customized battery voltage range
- ✔ DC-output current
- ✔ CAN communication
Highly Position Tolerant Inductive Charging System

<table>
<thead>
<tr>
<th>Nominal power</th>
<th>3 kW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Efficiency</td>
<td>94%</td>
</tr>
<tr>
<td>Operating frequency</td>
<td>≤150kHz</td>
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</tbody>
</table>

Case I
- Primary coil system
- First coil layer
- Second coil layer

Case II
- secondary coil system
Smart Energy Storage

Vision:
Battery Integrated Electronics
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Smart Battery System

Contactless signal transmission

Cell monitoring and balancing

Cell stack

Manual service disconnect

Main switch

DC link precharge discharge

Cell heating

Aux switch

S-Bat CAN

Battery Management Unit (BMU)

Thermal management and cooling system

Electrical insulation monitoring

High voltage insulation

Thermal insulation

14V Power-Net

Mobile AC socket

System CAN

E-Drive bus

Charging connector

E-Car controller

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Smart Battery Systems

Modular Battery Cell Stack (incl. cell monitoring and active l)
- LiFePO₄ cells (A123)
- Nominal voltage: 320 V
- Energy: 2.4 kWh

ICE Starter Battery (14 V)

14V Power-net DC/DC Converter (14.4 V, 2.5 kW)

High-voltage DC/DC Converter  Multi-functional V2G Interface (charger)

BMU (battery management unit)
Thank You for Your Attention

Your Partner in Automotive System Integration

Dr. Bernd Eckardt
Tel. +49 (0)9131 761139
Mail: bernd.eckardt@iisb.fraunhofer.de