# Institute for Power Electronics and Electrical Drives
# ISEA

Univ.-Prof. Dr. ir. Rik W. De Doncker

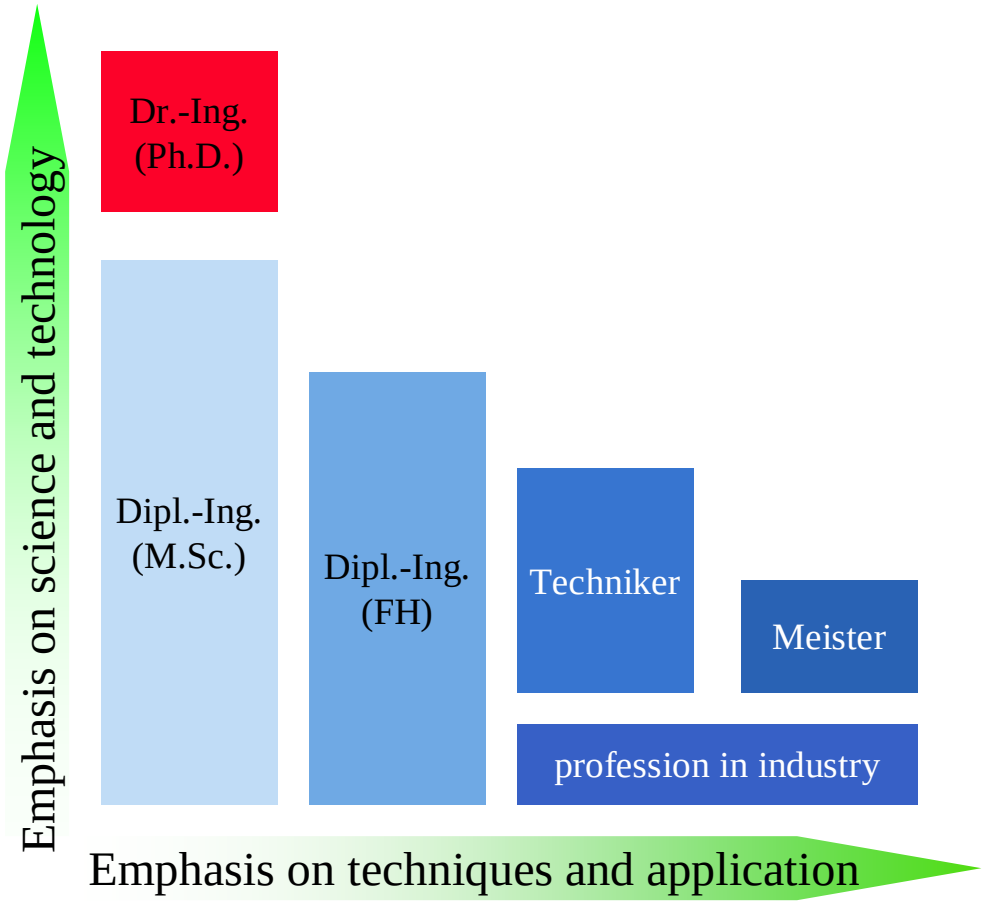
RWTH Aachen University

# Contents

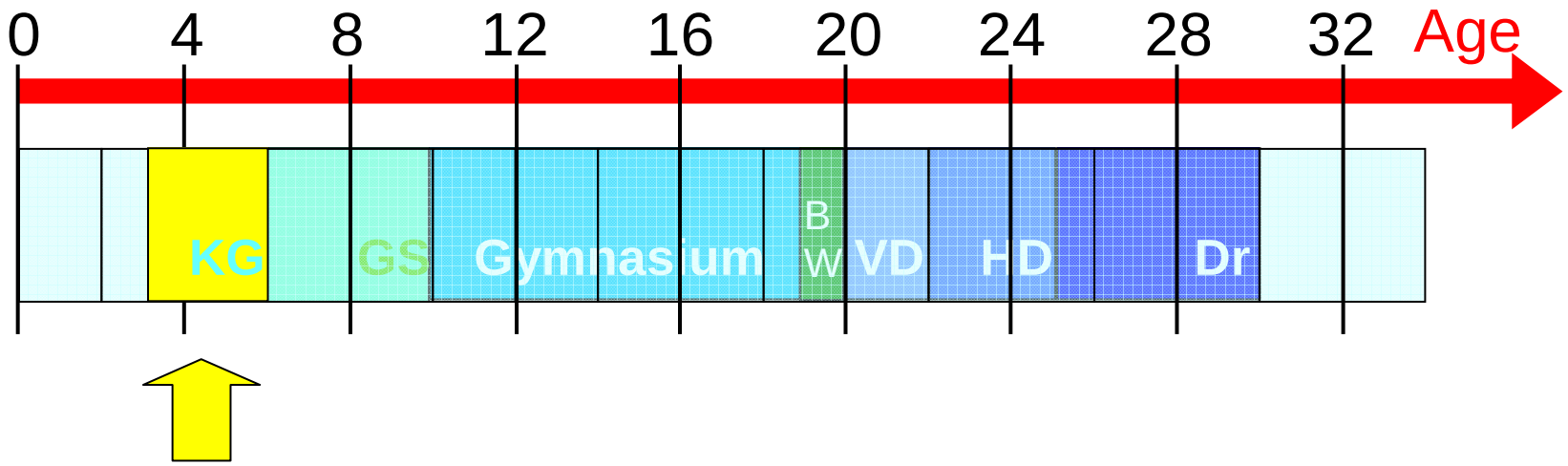
- Technical Education System in Germany
- RWTH Aachen
- Institute for Power Electronics and Electrical Drives (ISEA)
- Spin-off companies

# Technical education in Germany

- Different profiles and university degrees
- Emphasis on science and application
- Qualification besides university studies
- Degrees are clearly defined and protected by law
- Horizontal structure for a variety of tasks in industry and personal preference

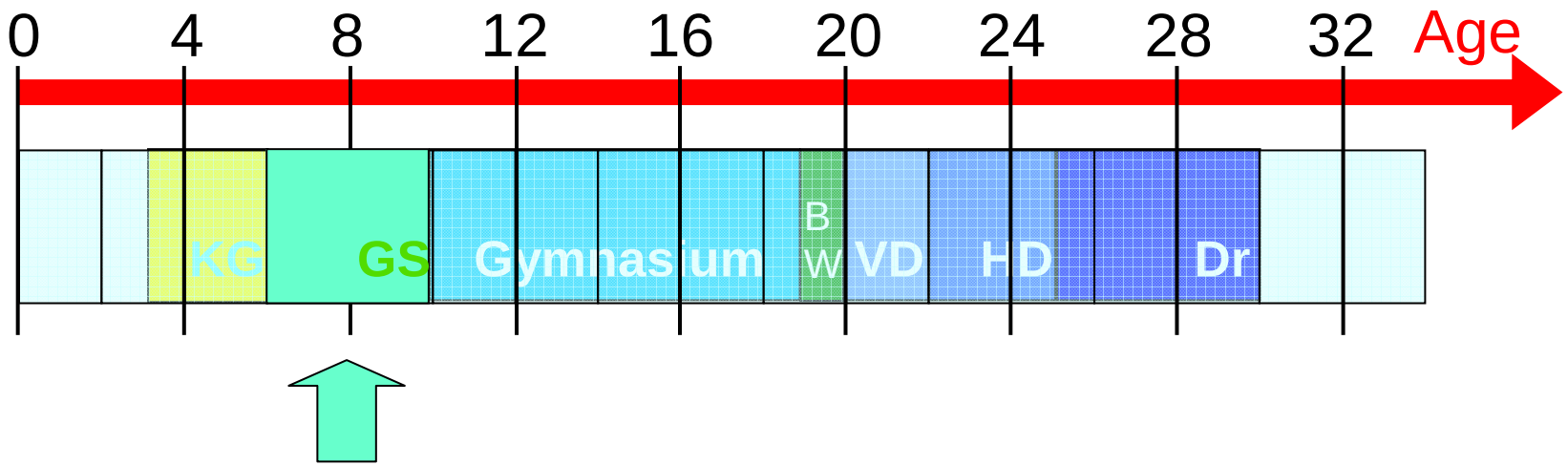


# Education Program of German Engineers




Kindergarten from age 3 to 6

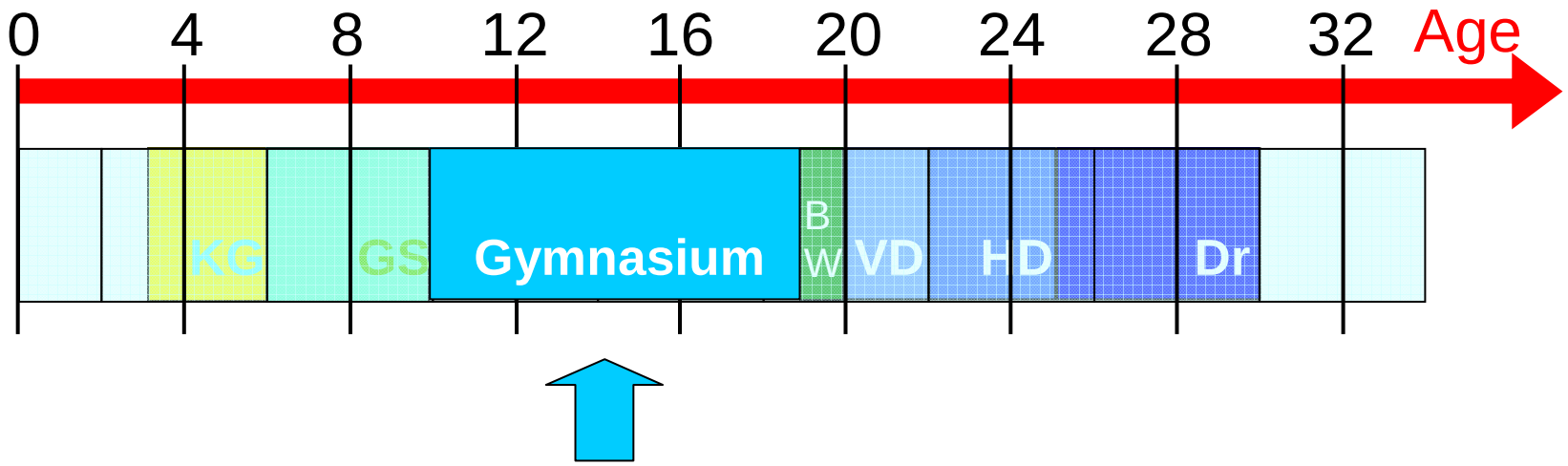
# Education Program of German Engineers




Grundschule (elementary school)

from age 6 to 10

# Education Program of German Engineers

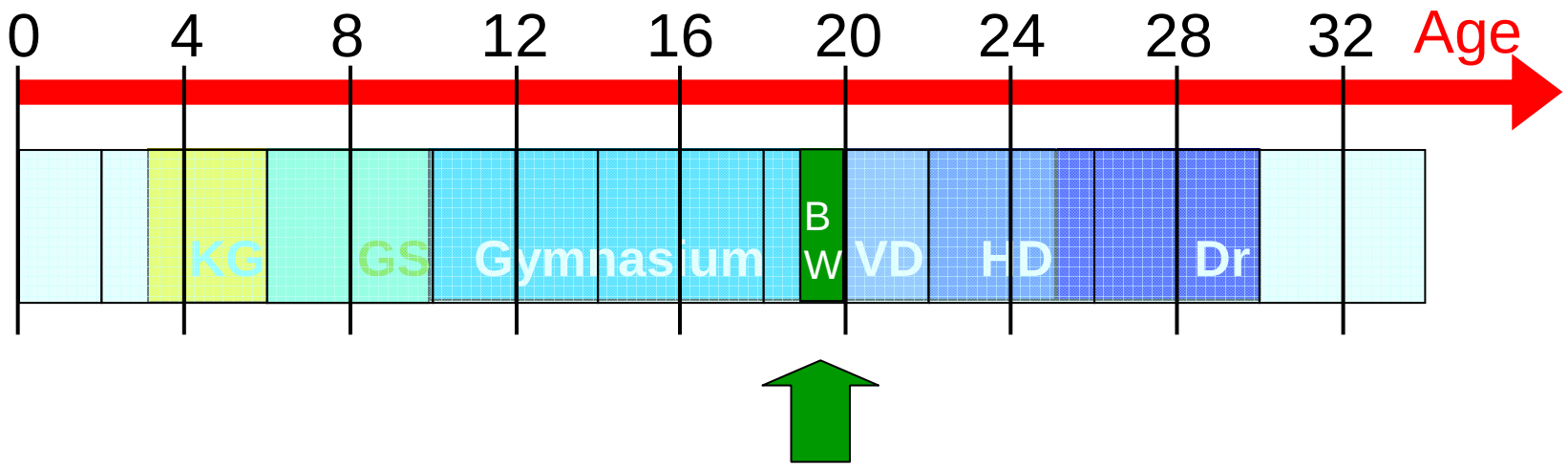



Gymnasium (middle and high school)

from age 10 to 19

Degree: Abitur (maturity exam)

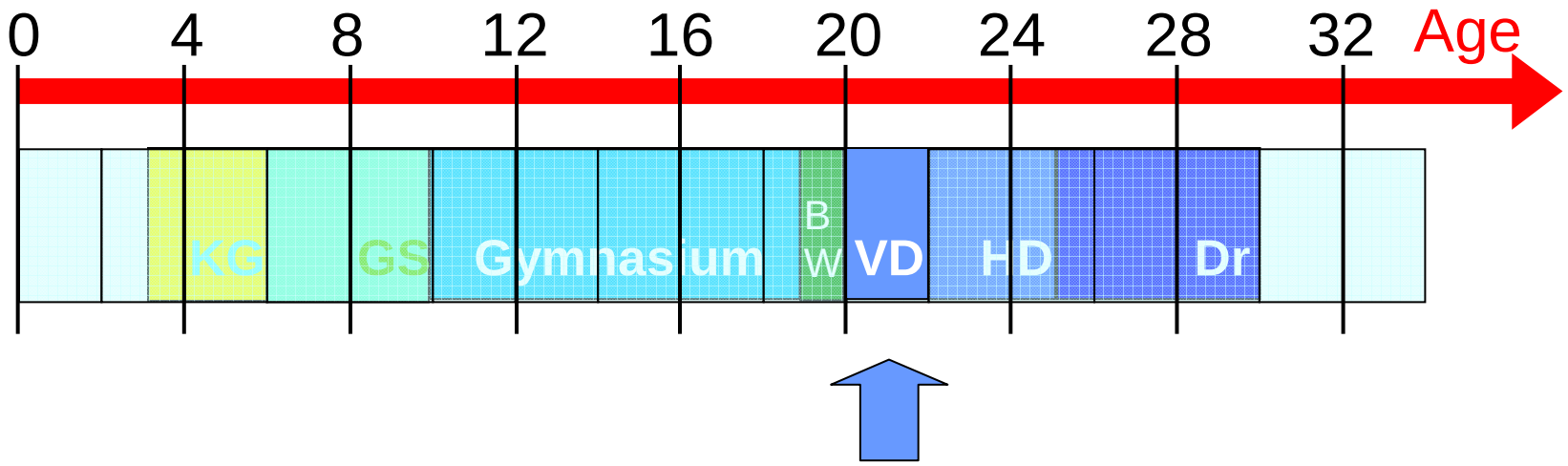
# Education Program of German Engineers




Bundeswehr (military or civil service)

from age 19 to 20

# Education Program of German Engineers

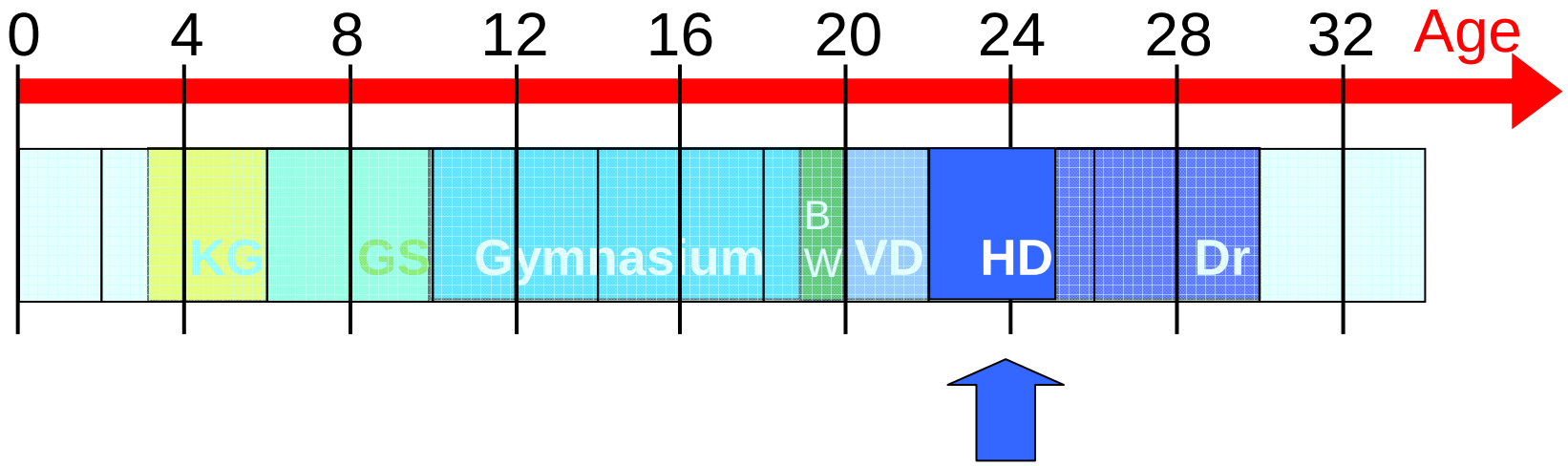



Vordiplom (candidacy)

from age 20 to 22 (4 semesters)

Abitur and Grundpraktikum (practicals) prerequisites

# Education Program of German Engineers



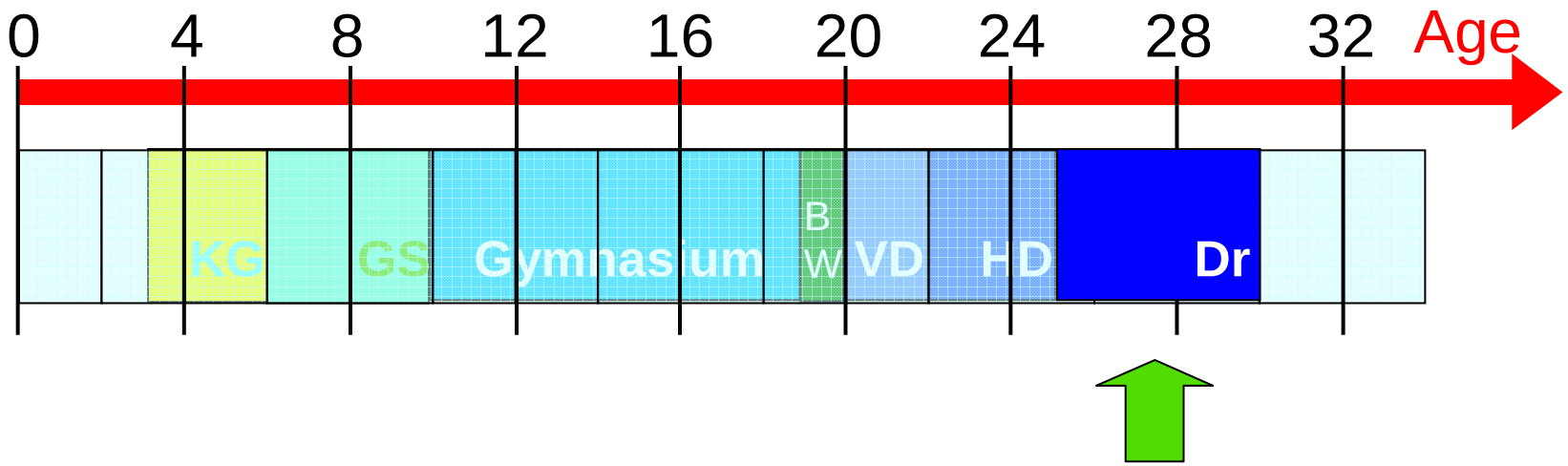

Hauptdiplom (technical studies)

from age 22 to 25 (5 semesters)

Fachpraktikum/Studienarbeit (practicals and report) prerequisite for thesis

Title: Dipl.-Ing.

# Education Program of German Engineers

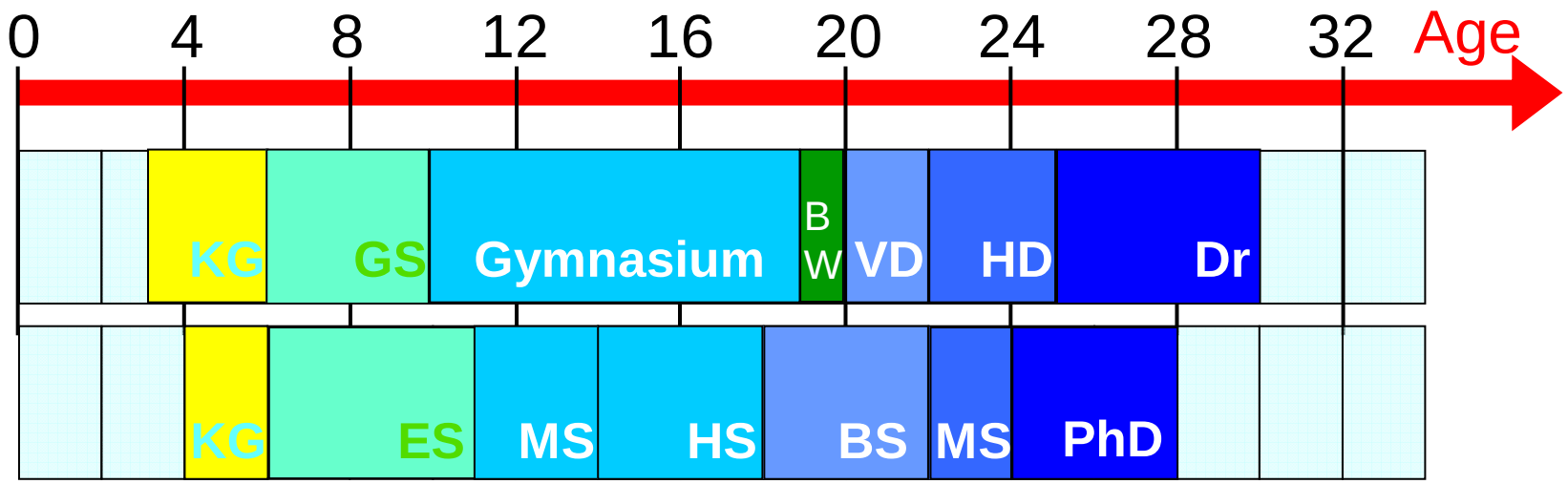



Assistentship (doctoral thesis)

from age 25 to 30 (max.  6 years)

Title: Dr.-Ing.

# US vs. German Education Program




Although first degree engineering studies are 1 year shorter, a **Dipl.-Ing.** (male) in Germany is:

- 3 years older than US **BS**
- 1 year older than US **MS**

**Dr.-Ing.** (male) in Germany is:

- 2 year older than US **PhD**

**However, this is only valid for the very best....**

# The RWTH Aachen Model

- The specific profile of Aachen University of Technology:
  - Education combined with advanced research and industry orientation (von Humboldt ethos)
  - Professors are expected to have profound industry management and research experience
  - Specialized courses taught by experts from industry (adjunct professors )
- The RWTH Aachen Model is based on high scientific demands combined with practice, interdisciplinary research and international references

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# Aachen

- health and spa resort since 1st century AD
- town of coronation (cathedral)
- important center for tourism and industry
  - machinery
  - processed food (marzipan, chocolate)
  - high-tech industry
  - automotive supplier
- population: 250,000

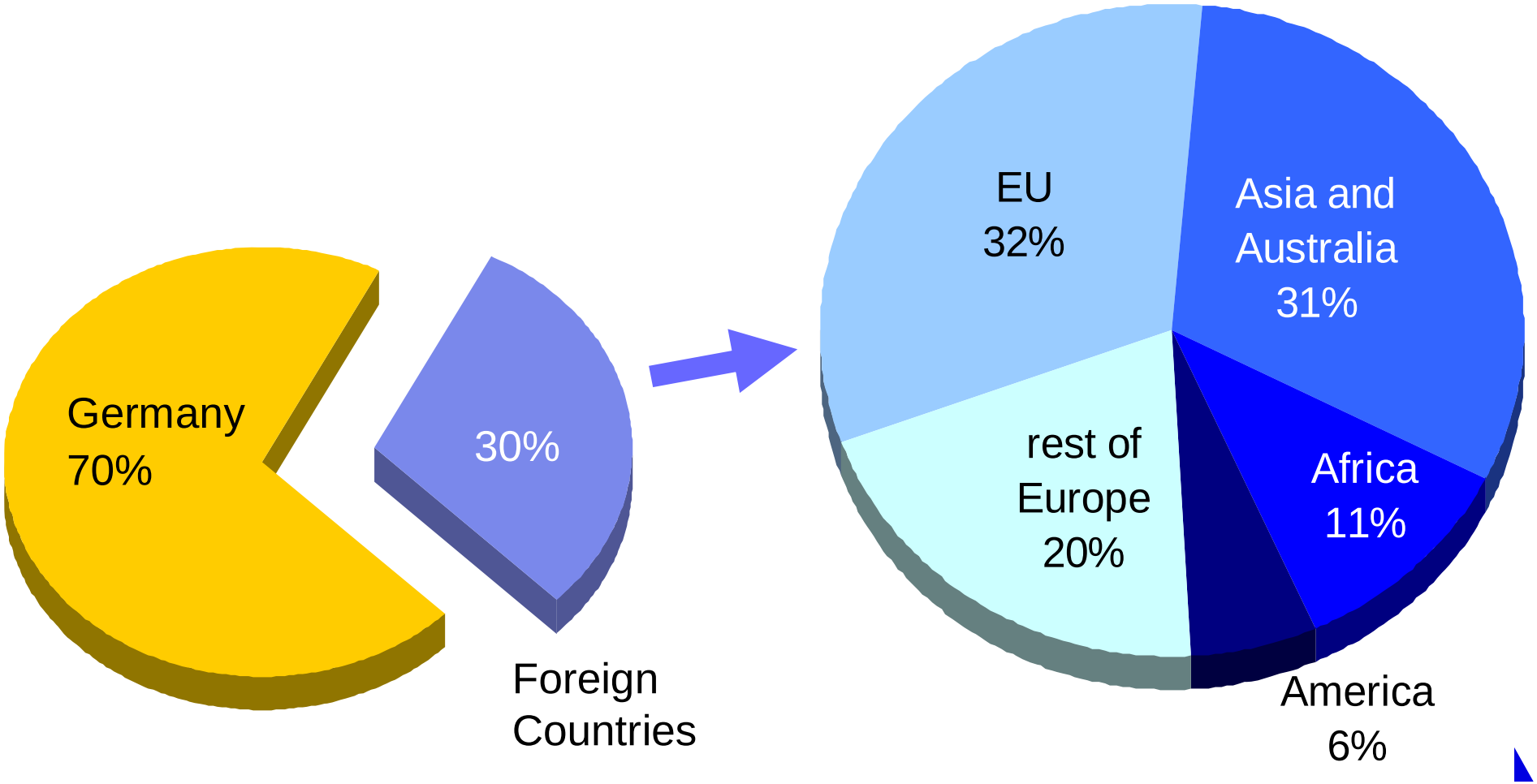
# RWTH Aachen University

- founded in 1870; one of the largest technical universities in Western Europe
- 110 degree courses
- 260 institutes and chairs;
  375 professors
- 28,500 students;
  2,200 graduates per year
- 10,000 employees
  - 1,965 research associates (RA's)
  - 1,735 industrial sponsored RA's
  - 700 apprentices and trainees

Quelle: RWTH Zahlenspiegel 2003

RWTH Main Building

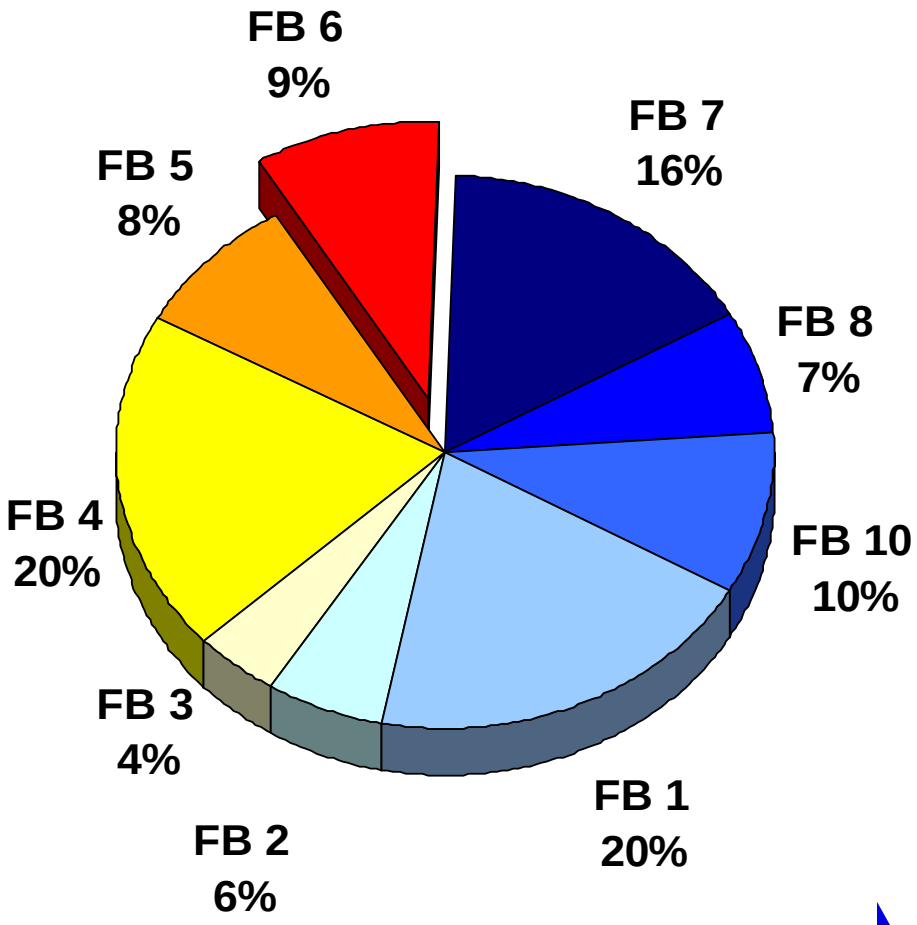
# Students from Foreign Countries 2004




Quelle: RWTH Zahlenspiegel 2004

# Student Numbers of RWTH Faculties (2004)

- FB 1: natural sciences, computer sciences, mathematics
- FB 2: architecture
- FB 3: civil engineering
- FB 4: mechanical engineering
- FB 5: georesources and materials engineering
- FB 6: electrical engineering
- FB 7: philosophy
- FB 8: economic science
- FB 10: medicine




Quelle: Zahlenspiegel der RWTH 2004

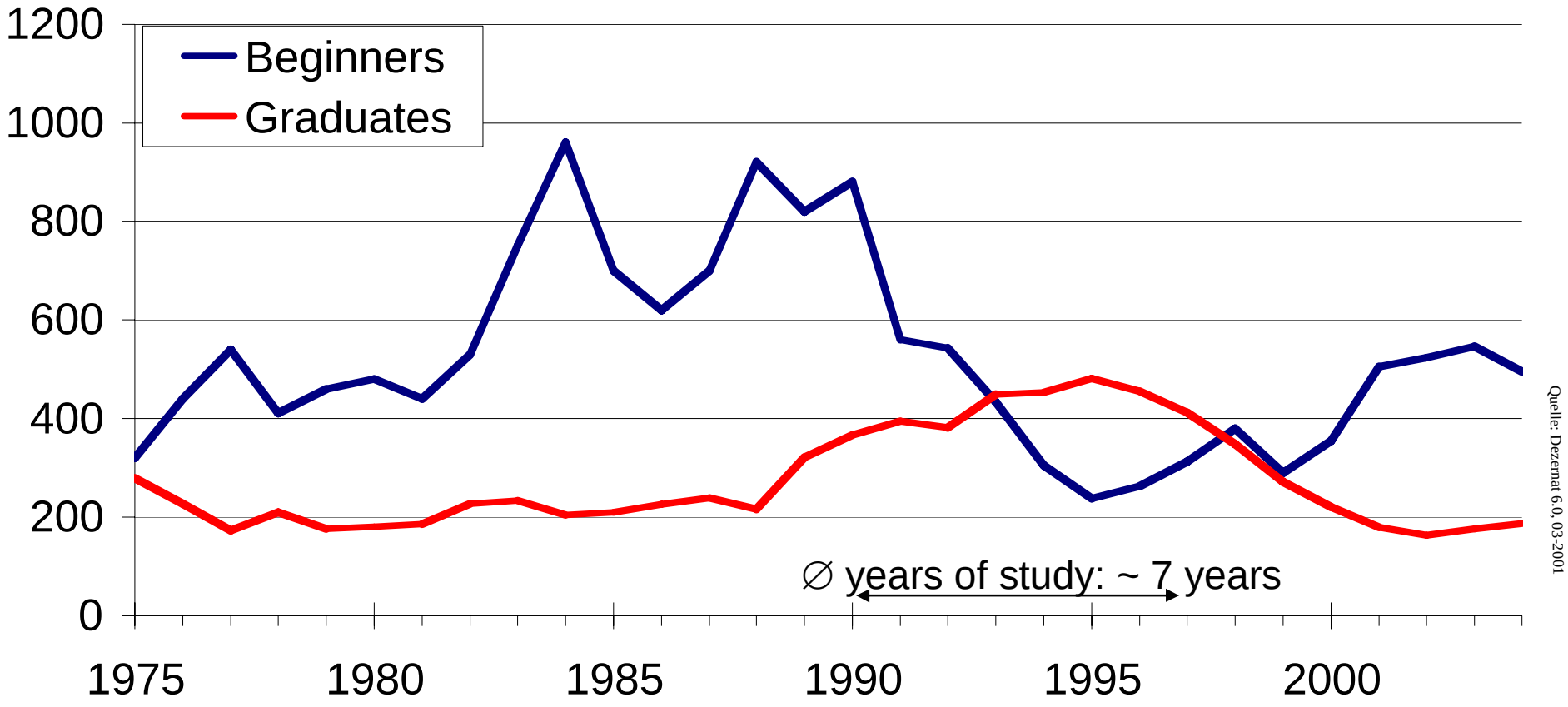
# Faculty for Electrical Engineering and Information Technology

- 23 institutes and chairs
- 27 professors
- 17 adjunct professors and lecturers from industry
- 280 research associates; 120 of them funded by industry
- 2,600 students; 187 graduates per year

- research areas:
  - Communication Networks
  - Electromagnetic Theory
  - Materials
  - Applied Computer Science
  - Biomedical Engineering
  - Semiconductor Electronics
  - High-Frequency Engineering
  - Technical Acoustics

Power Engineering
  - High-Voltage Engineering
  - Power Systems
  - Electrical Machines
  - Power Electronics and Drives

# Student in Electrical Engineering at RWTH



# International Master Program in Electrical Power Engineering

- Thorough theoretical foundation and hands on experience in electrical power engineering
- 2 year program
  - 3 semesters lectures
  - 3 months internship
  - 3 months master thesis
- Requirements:
  - Bachelors degree or equivalent
  - Above average grade
  - Language skills

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# Institute for Power Electronics and Electrical Drives (ISEA)

**Univ.-Prof. Dr. ir. Rik De Doncker**

**Power Electronics**
**Electrical Drives**
**Electronic Devices**

**Prof. Dr.-Ing. Adolf Müller-Hellmann**

**Electrical Transportation Systems**
**Railway Drives**

**Prof. Dr.-Ing. Heinz van der Broeck**

**Switching Power Supplies**

**Prof. Dr. rer. nat. Dirk Uwe Sauer**

**Electrochemical Energy Conversion and Storage Systems**

**Institute**

**Jaegerstr. 17-19**
**52066 Aachen**
**www.isea.rwth-aachen.de**
**post@isea.rwth-aachen.de**
**Tel: ++49/(0)241/80-96920**

# Institute for Power Electronics and Electrical Drives (ISEA)

**Prof. Dr. ir. Rik De Doncker**

- 1 junior professor, 2 chief engineers
- 2 adjunct professors
- 28 research associates
- ca. 35 part-time student co-workers
- ca. 35 graduate students per year
- 12 permanent staff
- 6 apprentices

**Institute**

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Power Electronics

Electrical Drives

Electronic Devices

Electrochem. Energy Conversion and Storage Systems


# Research Areas

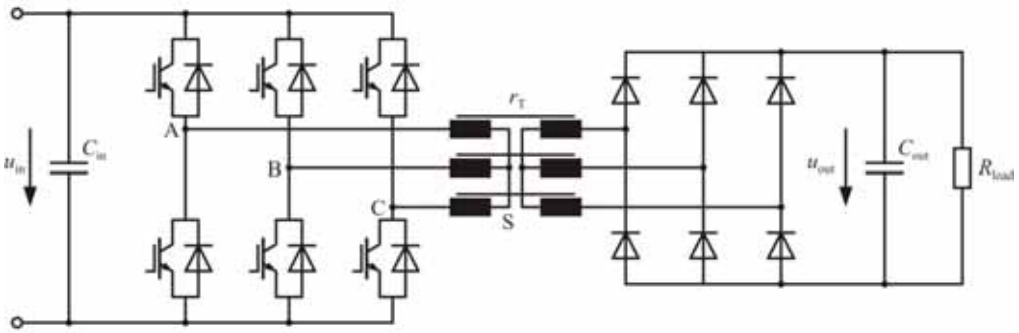
- High Power Team
  - high power devices
  - gate drivers
  - series connection of devices
  - active clamping
  - medium-voltage converter
  - medium-voltage current limiters
  - medium-voltage DC transmission

- LaMP Team
  - DC-DC converter topologies
  - power factor correction
  - contactless power transmission
  - converters for PV-systems
  - fuel-cell electric vehicles
  - converters for specific applications

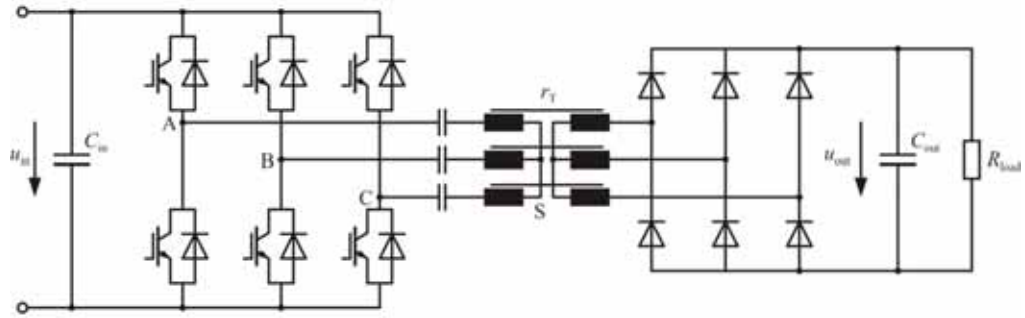
- common topics
  - reliability investigations
  - Life Cycle Costs (LCC)
  - EMC

# MIC - Topologies for the DC/DC Converter

- Three-Phase Single Active Bridge
  - Transformers stray inductance $L_\sigma$ is used for control
- Three-Phase Series Resonant Bridge
  - In case $L_h > L_\sigma$ , **not** $L_h >> L_\sigma$ ; then: Behaviour of a series-parallel resonant converter
- Why Three Phases?
  - Con
    - high number of devices
  - Pro
    - low stresses on active devices
    - very low stresses on passive devices
      - 600nF input capacity @ max. 60V, 150 W



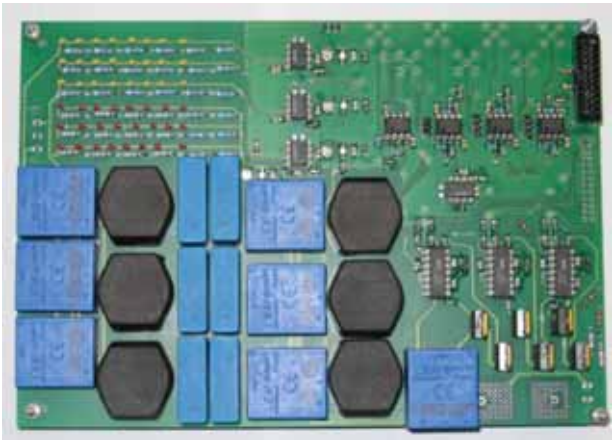

Three-Phase Single Active Bridge



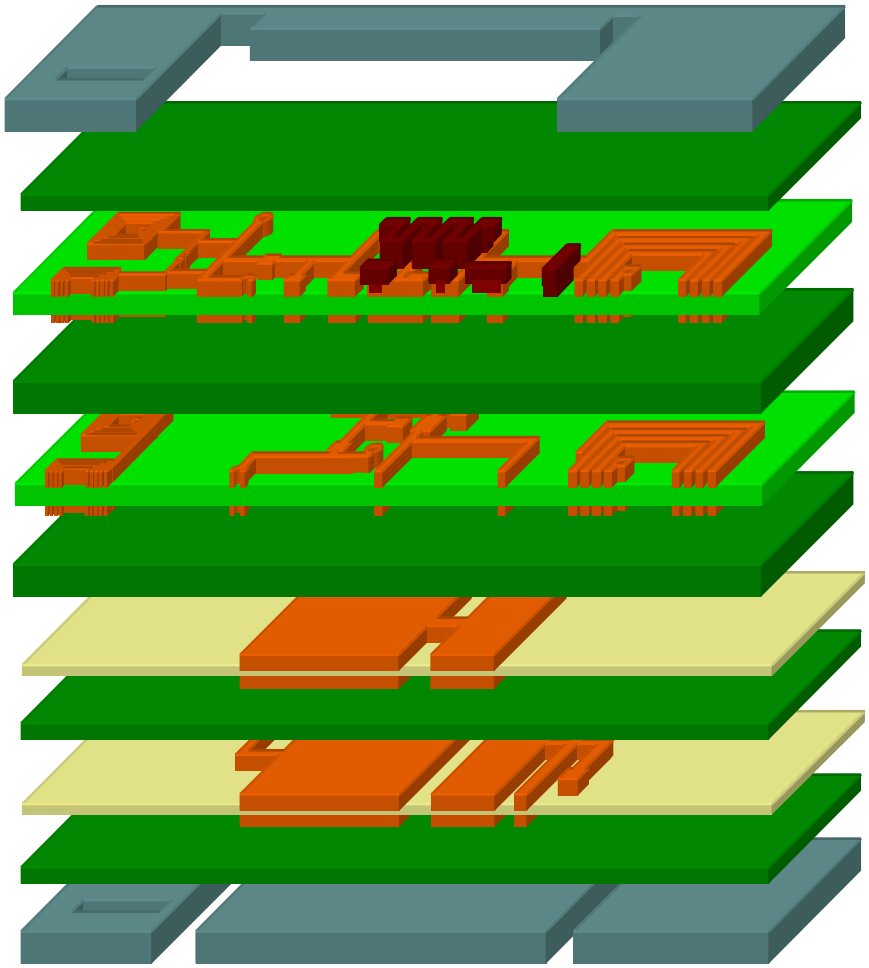

Three-Phase Series Resonant Bridge

# MIC - Integrated Power Electronics with emPIC

- emPIC: Embedded Passives Integrated Circuit



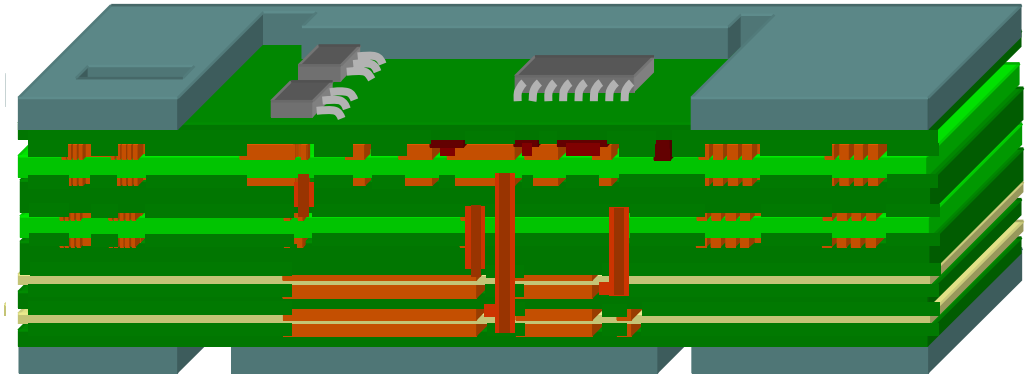
**Conventional three-phase MIC Prototype**



**MIC with empic Concept © Philips**

# MIC - Integrated Power Electronics with emPIC

- Costs:
  - standard and well known lamination process
  - low cost plastic compound materials are used
  - assembly of passives not applicable
- Current ISEA activity:
  - integration of the DC/DC converters' three phase transformer ($L_h > L_\sigma$)
- Lifetime:
  - High thermal conductivity in monolithic block
  - Hot Spots Avoided
  - natural convection is fostered by flat construction
  - Reduced temperature stress
  - Increased Lifetime



**MIC with empic Concept**
**© Philips**

# PV String Inverter - New Concept

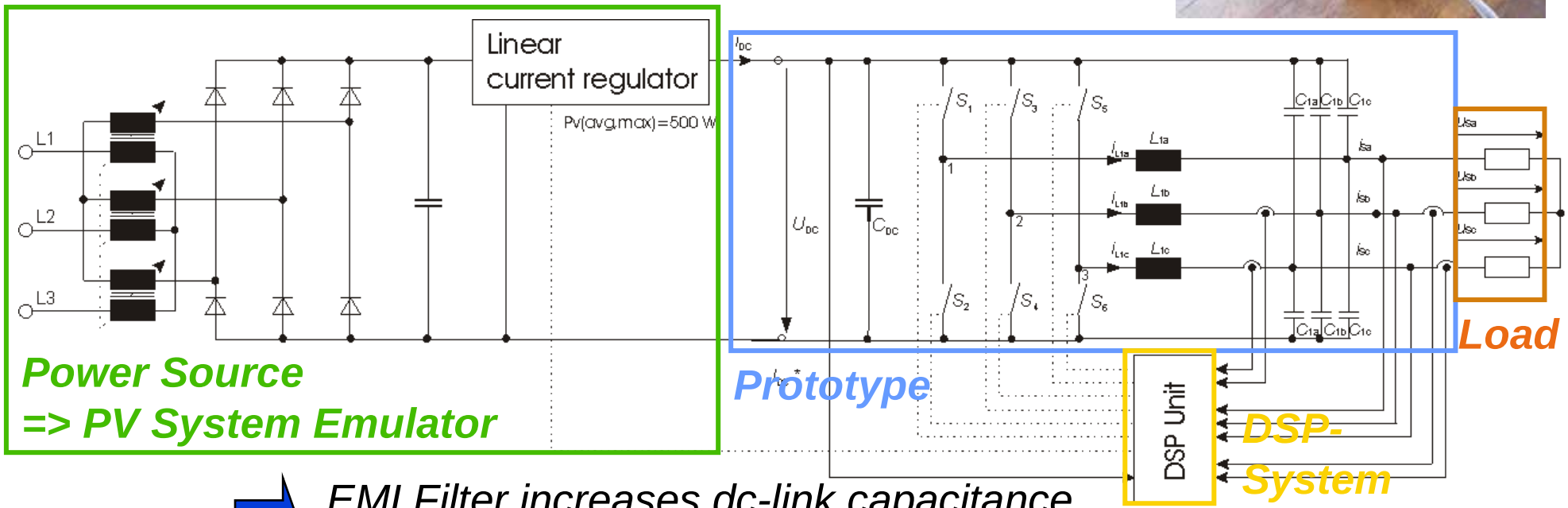
- Prototype and Experimental Setup - 5 kW

**$L_1$ = 120 µH, PQ35 core with 3C96**

**$C_1$ = 2 x 5 µF (MKS), $C_{DC}$ = 2 µF (MKP)**

***$S_1$..$S_6$: APT10035LFLL MOSFET with $R_{DSON}$ = 350 mΩ***

**$R_{Load}$ = 50 Ω**

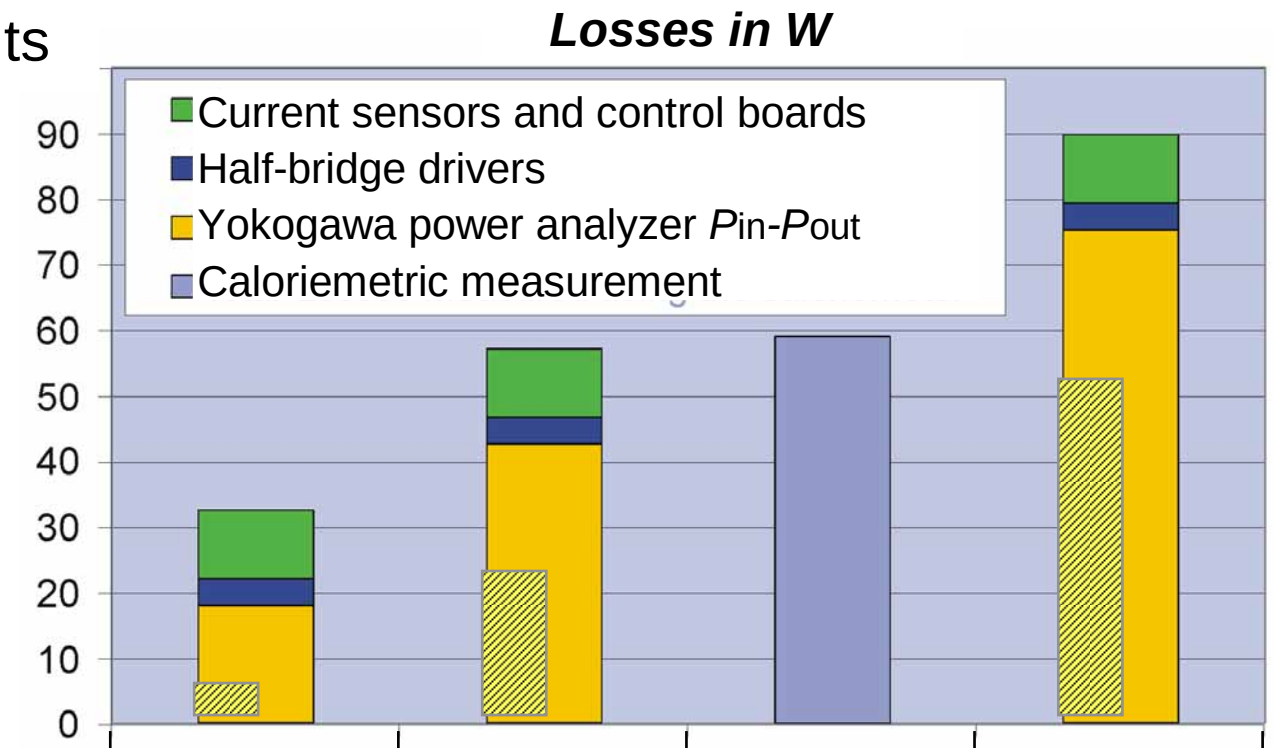



*EMI Filter increases dc-link capacitance*
*Easier compensation of capacitor loading currents*

# Grid Connection of Photovoltaic Systems - New Concept

- Measurement Results

***Caloriemeter***

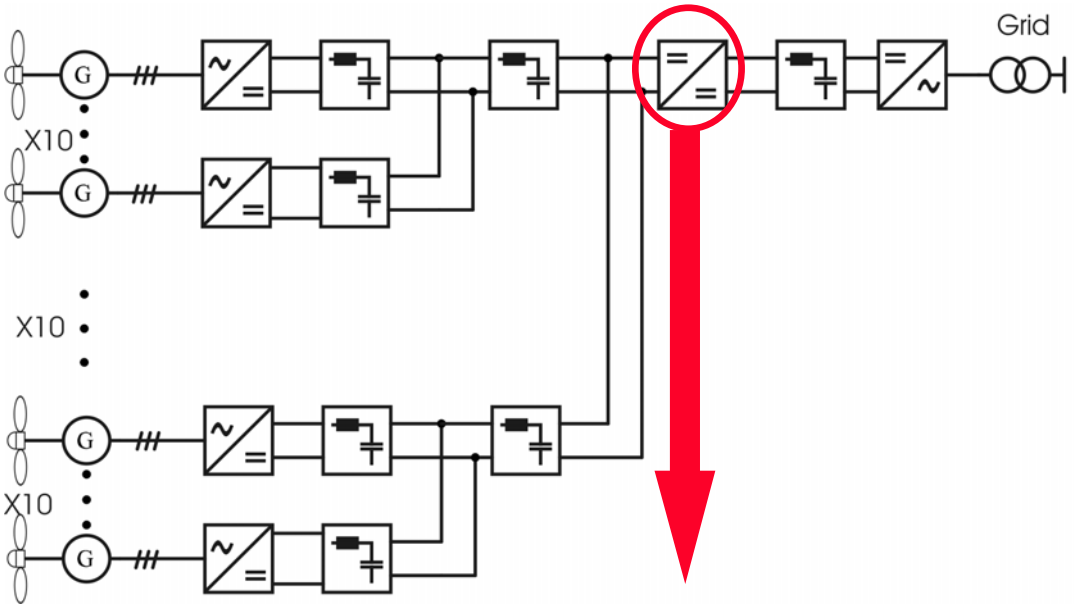


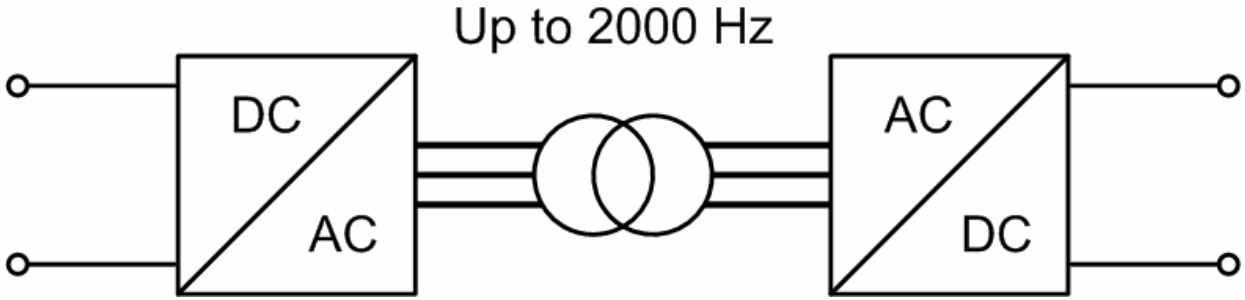

| | | | | |
|---|---|---|---|---|
| ***Input Power*** | ***1.5 kW*** | ***3 kW*** | ***3 kW*** | ***4.7 kW*** |
| ***Efficiency including Control*** | ***97.9 %*** | ***98.1 %*** | ***98.1 %*** | ***98.1 %*** |
| ***Efficiency excluding Control*** | ***98.8 %*** | ***98.6 %*** | ***98.5 %*** | ***98.4 %*** |

MOSFET conduction losses

# Multi-Megawatt DC/DC Converter for Wind Farms

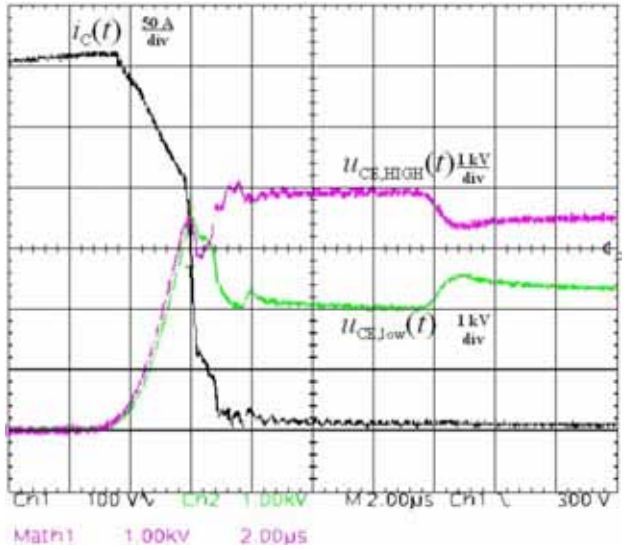
- Offshore Wind Farms
  - High power level
  - Long transmission length
- DC Grid could be advantageous
  - Voltage Step-up is inevitable
- DC/DC Converters
  - Medium frequency 25 MW transformer
  - Special design of transformer needed

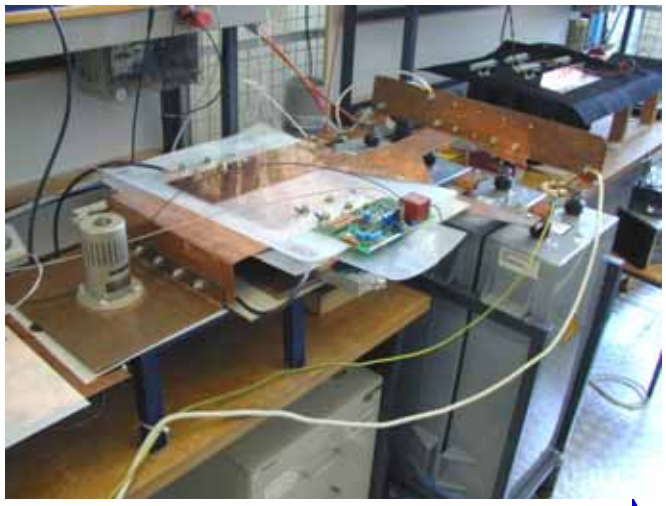


# High-power / medium-voltage test lab

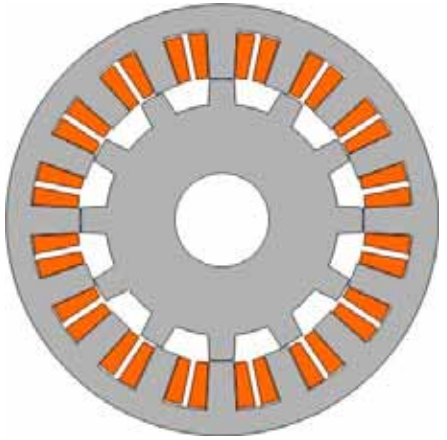
- Labview controlled
- Automatic characterization of devices
  - Turn-on losses
  - Turn-off losses
  - On-state losses
- Ratings
  - 0...12 kV
  - 0...5 kA
  - -10...125 °C
  - 200 MHz
- Testing
  - Series connection
  - Hard- and soft-switching
  - Resonant switching
  - Short circuit behavior
  - Gate-Drive development
- Press-Pack & Module housings
- Test bench for continuous operation (3 kV, 2 kA)



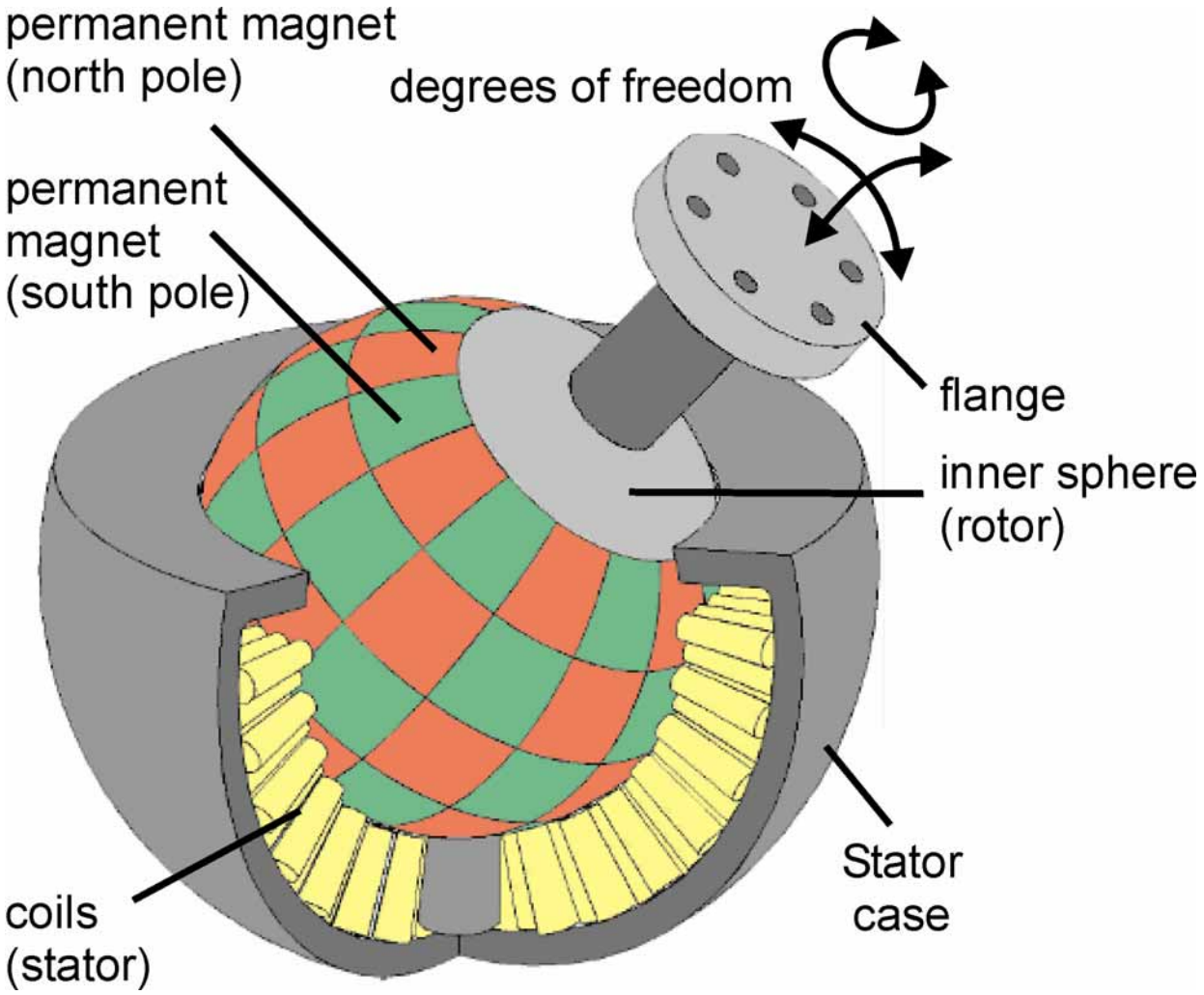



# Research Areas

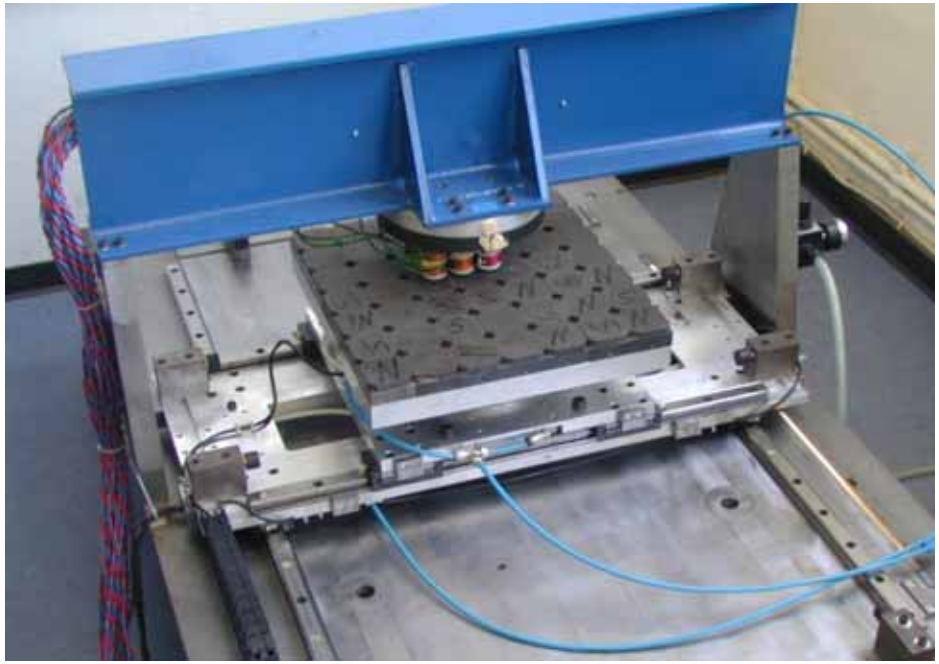

- Switched Reluctance Drives
  - converter and machine design
  - simulation
  - torque control
  - sensorless control techniques
  - cooling methods
  - integrated drives (machine + converter)
  - machine acoustics
- Drivetrain Modeling
- Measurement and Evaluation of Electrical Drives
  - 15 kW / 100 kW test benches
  - 120 kW drivetrain test bench
  - acoustic evaluation
  - automated characteristic measurement of switched reluctance machines

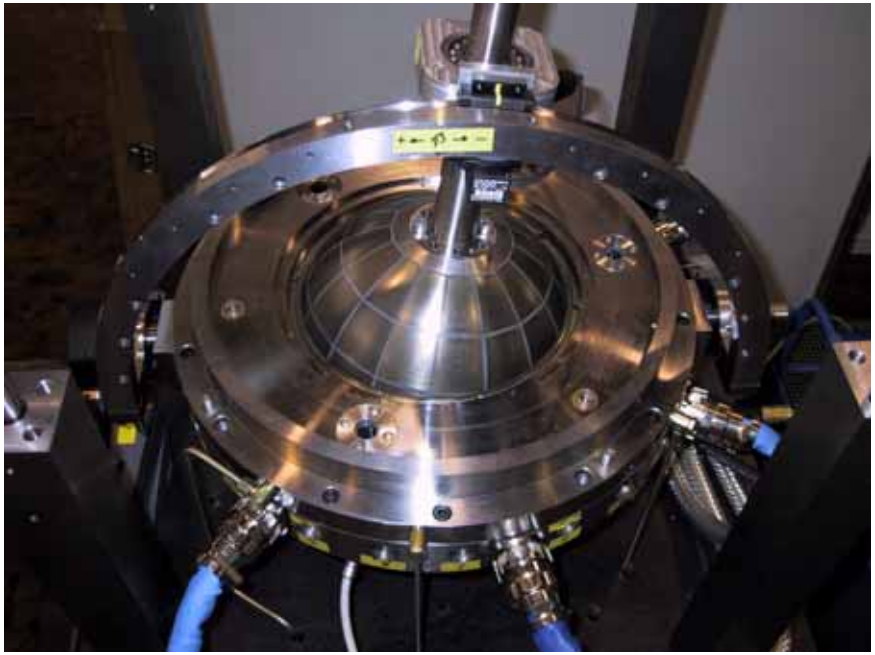


# Spherical Machine Concept

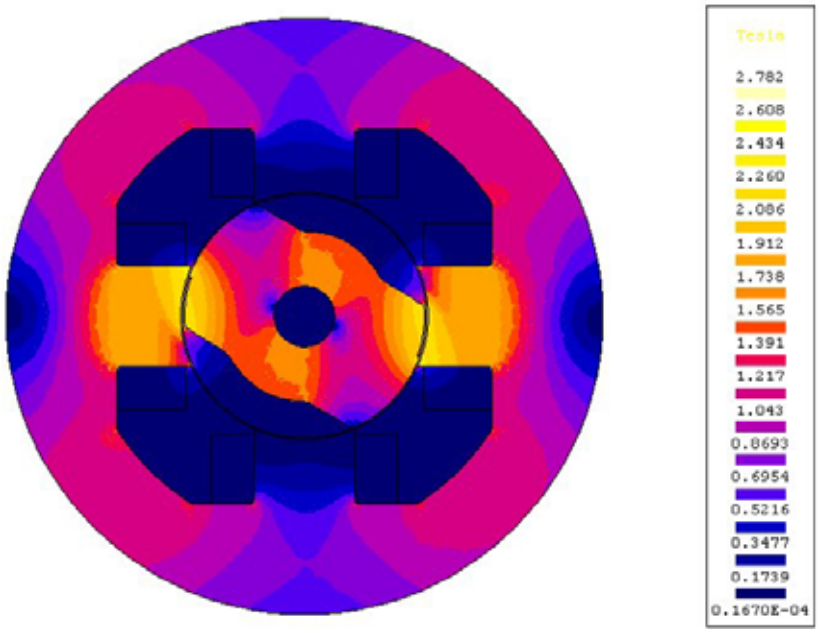


# Test Bench: Planar Motor and Spherical Motor





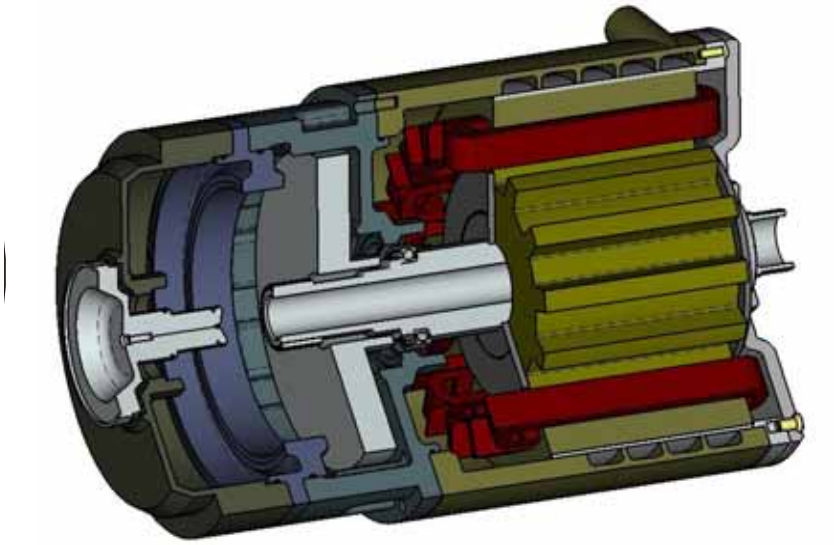
# Antriebe für Staubsauger




| | |
|---|---|
| **Phasenanzahl** | **2** |
| **Polkonfiguration** | **4/2, 8/4** |
| **Nenndrehzahl** | **35.000 Upm** |
| **Nenndrehmoment** | **0,25 Nm** |
| **Nennleistung** | **1,5 kW** |

- **kompakter Umrichter**
- **Gewichtsreduzierung**
- **Netzrückwirkungen**
- **Geräuschoptimierung**

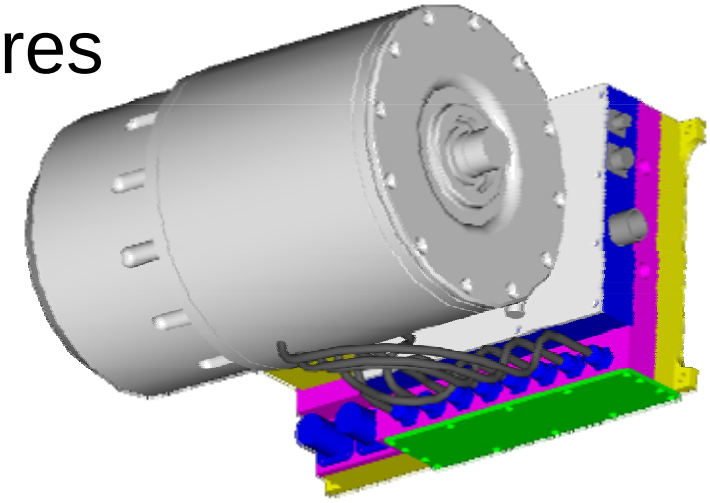
# *OKO*FEH (Optimized Components for Electric and Hybrid Vehicles)

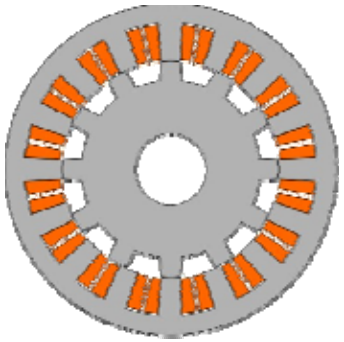


**Technical Data:**

| | |
|---|---|
| **Phases** | **4** |
| **Pole Configuration** | **16/12** |
| **DC Voltage** | **300 V** |
| **Max. Speed** | **12.000 rpm** |
| **Nominal Torque** | **155 Nm** |
| **Peak Torque** | **220 Nm** |
| **Nominal Power** | **55 kW** |
| **Peak Power** | **80 kW** |
| **Active Weight** | **50 kg** |

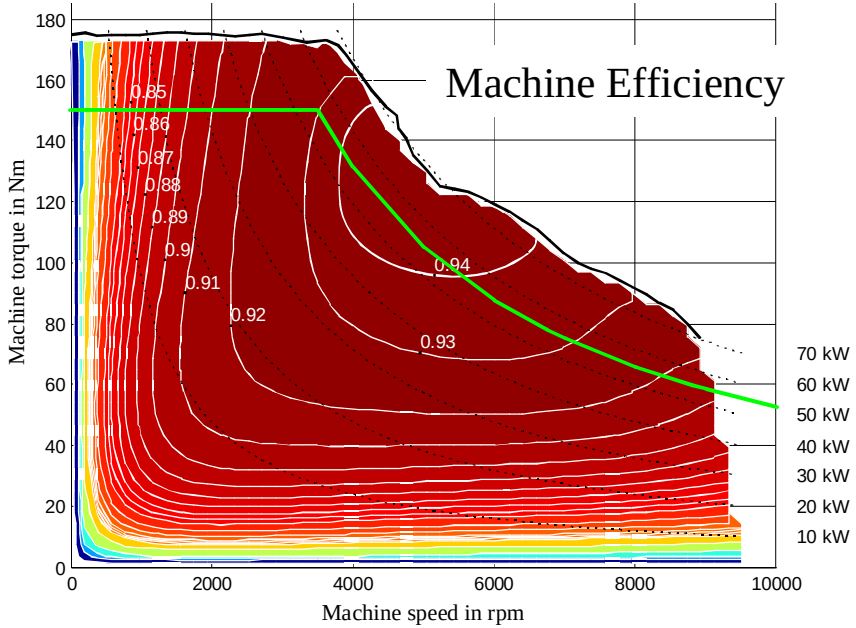
- Drive System Features
  - Transaxle Design
  - DATC Torque Control
  - Compact Converter
  - CAN Communication
  - Water Cooling

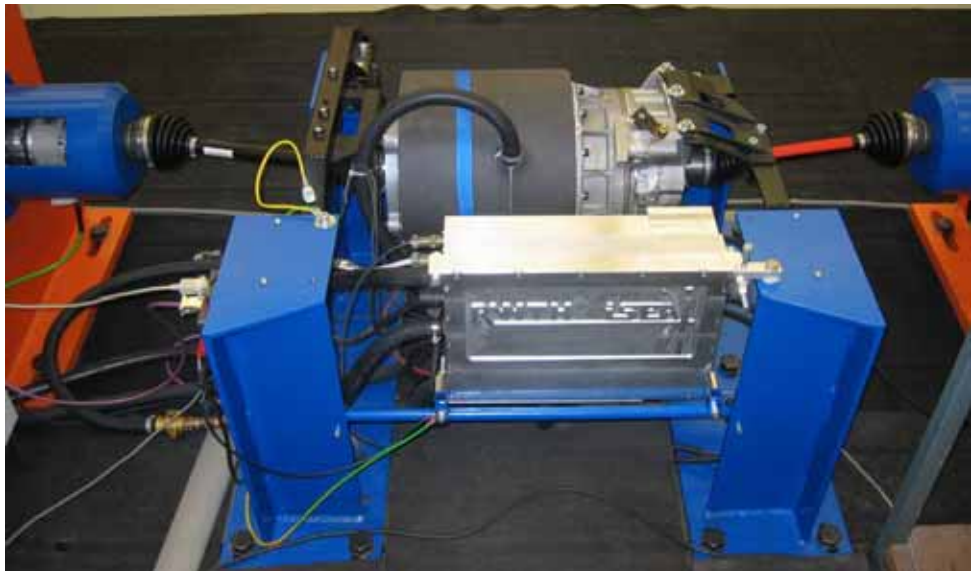




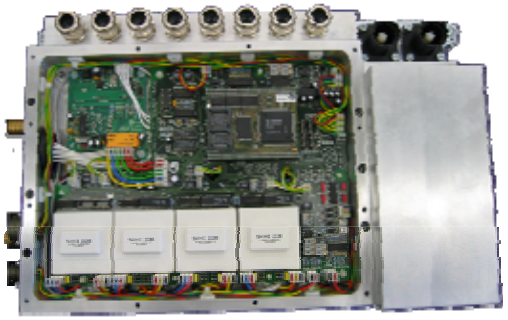
# *OKO*FEH (Optimized Components for Electric and Hybrid Vehicles)

- Measurements on ISEA Drive-Train Testbench
  - Converter Efficiency
  - Drive-Train Efficiency
  - Continuous Power
  - Thermal Limits
  - Drive Dynamics

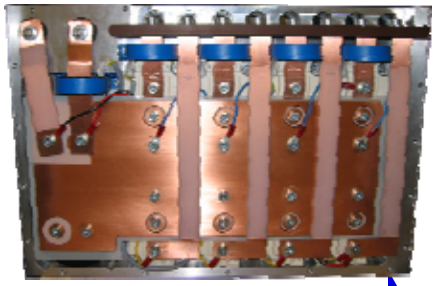


Testbench Setup



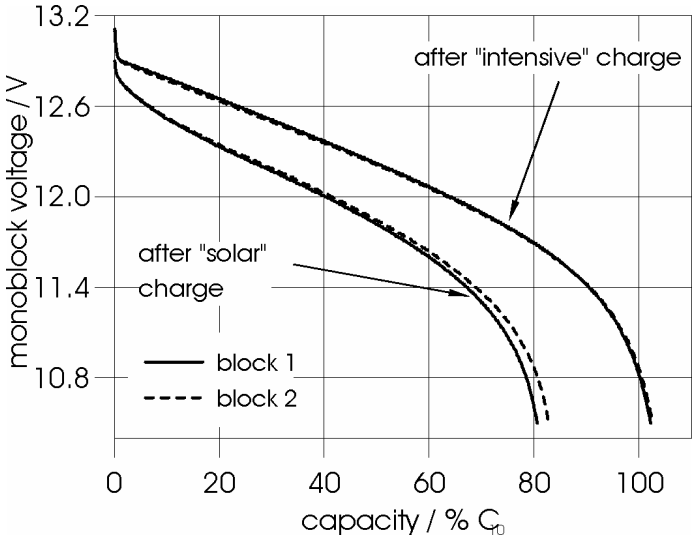
Controller



Power Stage

# Research Areas

- characterization and modeling of batteries (lead-acid, lithium-ion, NiMH, NiCd), SuperCaps and fuel cells
- investigation and development of energy and battery management systems incl. prediction of cranking capability and state of charge
- development of dynamic and ageing simulation models
- optimization of charging strategies & electronics
- development and application of impedance spectroscopes for diagnosis & characterization
- design of new battery materials (lithium)
- **areas of applications: automotive, hybrid cars, autonomous power supplies (e.g. PV)**

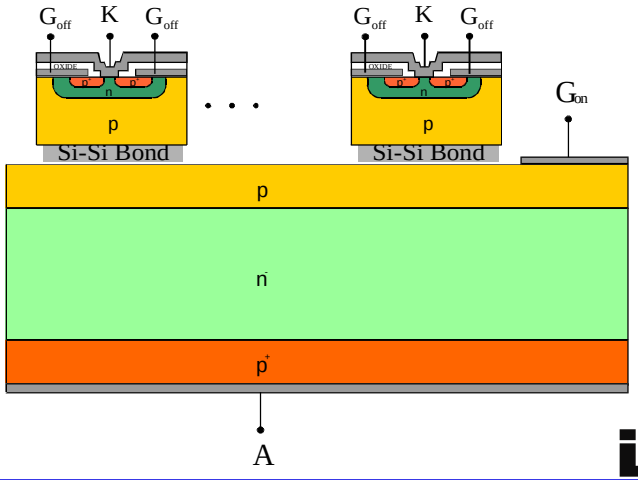




Prof. Dr. Dirk Uwe Sauer


# Research Areas

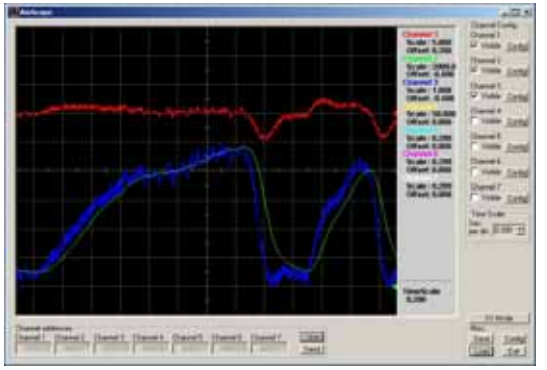
- 1000 m$^2$ clean room
- chip-on-wafer bonding technology
- Si-Si bonding interface characterization
- development and assessment of novel packaging-concepts
- modeling and simulation of high-power semiconductors (e.g. FEM)
- low-cost, high-power semiconductor device technology

# Contents

- Technical Education System in Germany
- RWTH Aachen
- Institute for Power Electronics and Electrical Drives (ISEA)
- Spin-off companies

- Development Tools for Power Electronics
- Rapid Control Prototyping
- Customer Specific Development



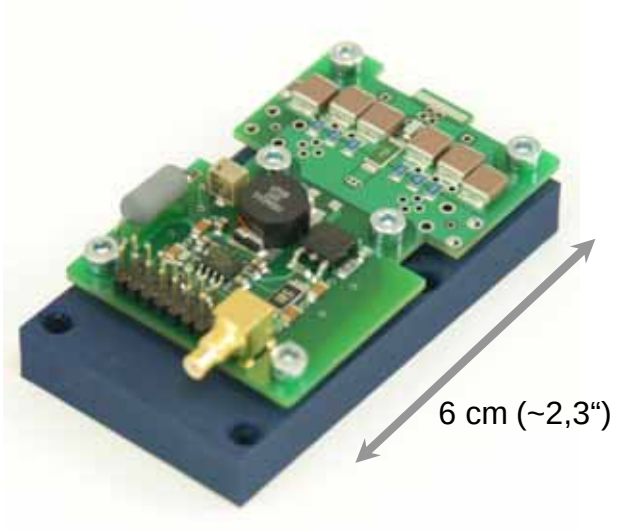
- Modular Power Rack XPR 2000
- Up to 5 voltage levels
- Up to 750 $V_{dc}$ or 50 $A_{dc}$
- ASM / SRM / Breakchopper modules

- Flexible Control System XCS2000
- 32 AD/DA channels
- PWM / ARCP control outputs
- Interface cards for direct Skiip® control
- Individual front connectors

- Online debugging tool
- Access via TCP/IP
- Analyzing actual data
- Modifying internal parameters

PicoLAS

- Pulsed Current Supplies
  - Pulse durations: 700 ps up to 10 µs
  - Load currents: 2 ... 600 A (@ up to 500 V).
  - Applications: Research (e.g. Organic-Laser materials), Measurements, ...
- Highly Dynamic Current-Sources
  - Modulation (100%): DC to 25 kHz (opt. 50kHz).
  - Load currents: up to 240 A @ 1.5 to 40 V.
  - Replaces: All cw and qcw Diode-Laser supplies.
  - Applications: Welding, Soldering, surface-treatment.
- Laser Systems
  - Pure Diode-Laser based marking system.
  - Customer Benefits: Higher Reliability (Lifetime > 100.000 h). Reduces system Costs to 50%.




# Institute for Power Electronics and Electrical Drives
# ISEA

Univ.-Prof. Dr. ir. Rik W. De Doncker

RWTH Aachen University