Power Electronics and Electrical Drives

Prof. Dr.-Ing. Joachim Böcker

Research Topics

Mechatronic Systems, Electrical Drives and Electric Vehicles

- Control, modeling and optimization of electrical drives, e.g.
  - Interior permanent magnet synchronous motors (IPMSM)
  - Switched reluctance drives
  - FPGA based control
- Self optimizing systems (Collaborative Research Center 614)
  - Optimal Energy management for (hybrid) vehicles and hybrid energy storage
- Electric vehicles
- RailCab

Power Electronics

- Switched-mode power supplies
- High efficiency topologies
- Resonant converters
- Digital control

Staff

Head of Department

Prof. Dr.-Ing. Joachim Böcker

- Full professor at Paderborn University since 2003
- Deputy vice dean of the Institute of Electrical Engineering and Information Technology, Paderborn University
- Executive board at Institute for Industrial Mathematics
- Share holder of the RailCab Development GmbH
- Senior member of the IEEE, member of VDE

Scientific staff

- More than 20 research assistants and graduate students

Technical staff

- Support for various test and measurement setups in the laboratories

Laboratory

Laboratory (450 m²)

- Conventional test benches for power electronics and drives
- Special test facilities for electrical drives, particularly automotive (S_{max} > 500 kVA)
- Air-conditioned cabin, water cooling/heating
- Wide range of motor types
- dSPACE prototyping systems
- Modern analogue and digital measuring instruments

NBP Test Track

- 530 m, 1:2.5 scale
- Linear motor, both active and passive stator

Mechatronic Systems, Electrical Drives and Electric Vehicles

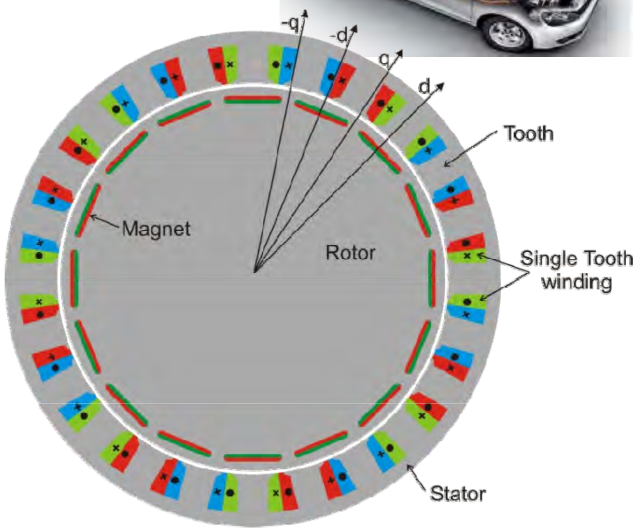
IPMSM Modeling & Control

IPMSM: Preferred Motor in Automotive Traction Applications

- High efficiency
- High power and torque densities

Research Topics

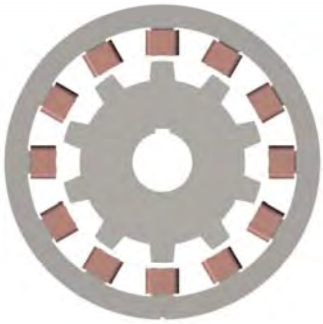
- PMSM / IPMSM Modeling
  - Electrical (Saturation, iron losses)
  - Thermal (Observer, LPTN)
- Efficiency Optimization
  - Operating point selection
  - Optimized pulse patterns
- Control
  - FOC / DTC
  - Model predictive (MPC)
  - FPGA-based



Switched Reluctance Drives

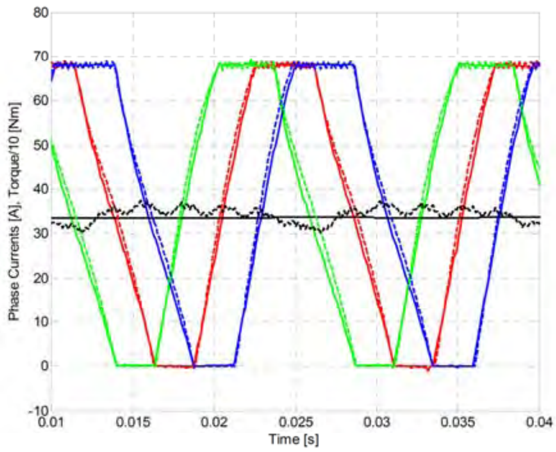
Robust and Simple Mechanical Structure

- Concentrated windings only on one part (stator vs. rotor)
- Rotor is thermally unsusceptible and shock-resistant
- Simple Converter structure
  - One asymmetric half-bridge per phase
  - Multiphase operation recommended



Complex control

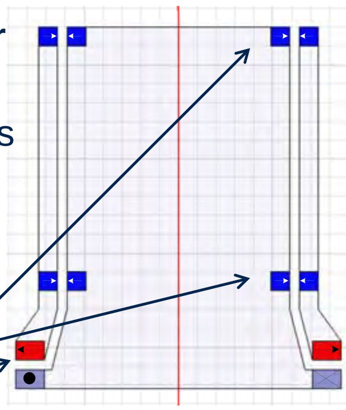
- Discrete control of each phase
- Inherent torque ripple
  → Noise generation
- High THD could interfere with other systems
- Efficiency and force density similar to ASM



Magnetic Bearing with Integrated Drive

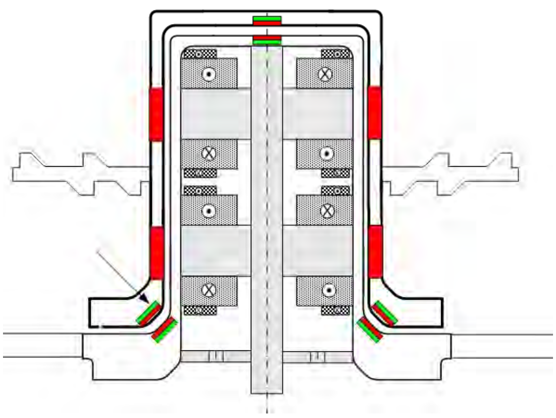
Design and control of a magnetically borne agitator for hermetic applications

- Passive radial bearing using permanent magnet rings
- Permanent Magnet Synchronous Motor integrated into the rotor outlines
- Active magnetic bearing in axial direction



Passive radial bearings

Active axial bearing



Benefits

- No Fluid pollution by ball bearing grease and abrasion
- No external drive needed
- No maintenance of wear parts
- Smaller outline

Design Environment E-Mobil

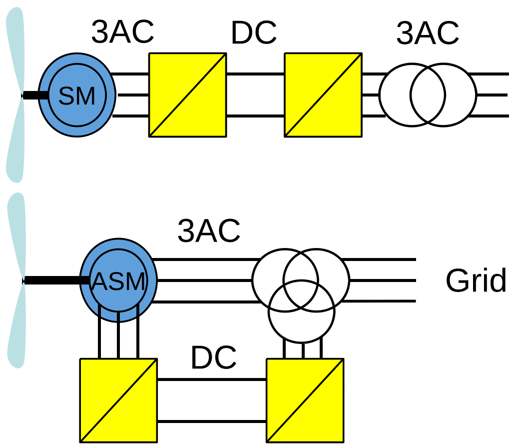
Simulation Supported Design of Electrical Vehicles

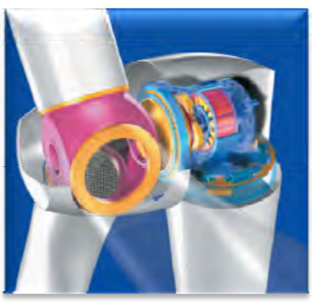
- Assistance with the developing procedures of electrical vehicles
- Optimization of the development process
  - Efficiency and savings potential
  - Model and virtual control unit tests
- Provision of essential design tools for standardized platforms

Windpower

Employment of a PMSM with integrated magnets instead of a doubly-fed ASM

- No energy transfer into rotor via collector rings (low maintenance)
- No need to synchronize with the grid due to existing DC link
- Variable speed operation to increase efficiency
- Gearless direct drive





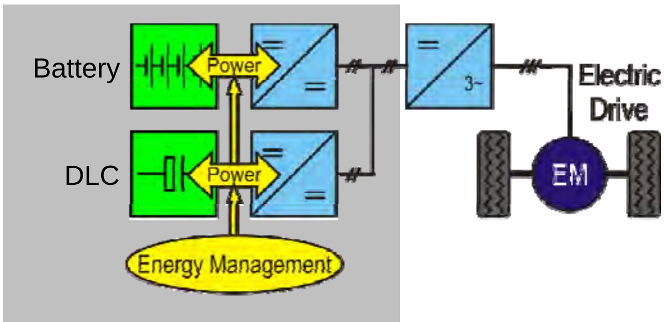
Development objectives

- Control structure for a permanent magnet synchronous generator with integrated magnets
- Reduction of switching losses in the converter by optimized driver strategies for the IGBT stack
- Routines for failures (fault ride through, blackout, …)

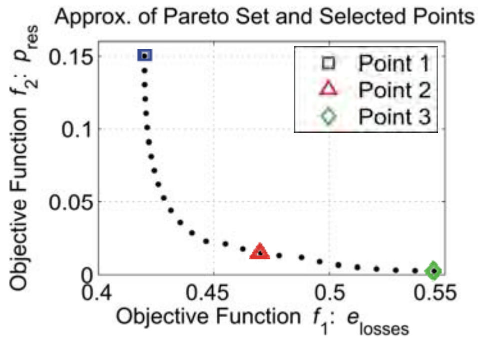
Energy Management for Hybrid Energy Storage

Efficient Storage for Electrical Energy: Hybrid Energy Storage System

- Combination of complementary storage technologies
  - Batteries (NiMH, Li-ion): Long term storage
  - Double layer capacitors (DLC): Short term storage
- Intelligent self-optimization operating strategies for energy management
- Variable relevance of objectives
  - Losses, efficiency
  - Power reserve
  - Life span



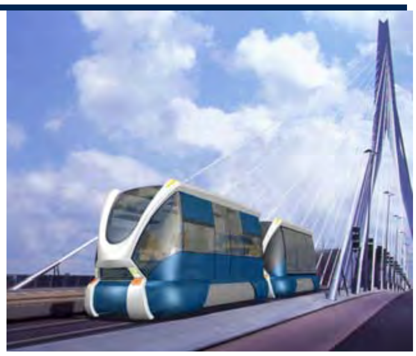
Hybrid Energy Storage System



RailCab

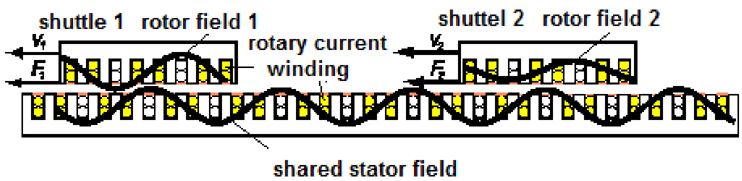
Novel Modular Railway System

- Small autonomous vehicles (shuttles)
  - Only direct connections without need to change trains
  - No distinction between local and long-distance traffic



Research Topics

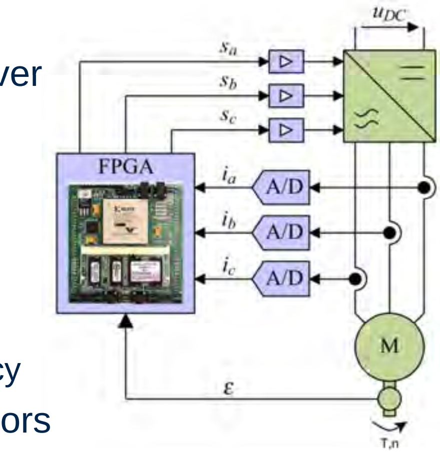
- Linear induction motor
  - Doubly-fed motor for contactless energy transmission
  - Alternatively operation with passive reaction rail (lower track costs)
- Hybrid energy storage system
  - Efficient buffer of energy and power in both batteries and double layer capacitors



FPGA-Based Motor Control

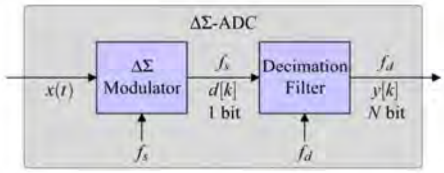
Advantages of Field Programmable Gate Arrays (FPGA)

- Flexible, fast and parallel processing
- Parallel execution of e.g. controller and observer
- Fast response with hysteresis-controllers



Research Topics

- FPGA-based quasi-continuous PWM controls
  - Better dynamics compared to regular sampled control without increasing the switching frequency
- Analog to digital conversion using ΔΣ modulators
  - Programmable ADC characteristics: Resolution vs. computation time
- Dynamically reconfigurable control structure
  - Adaptation to varying operating conditions
  - Better fault tolerance (e.g. to sensor failures)

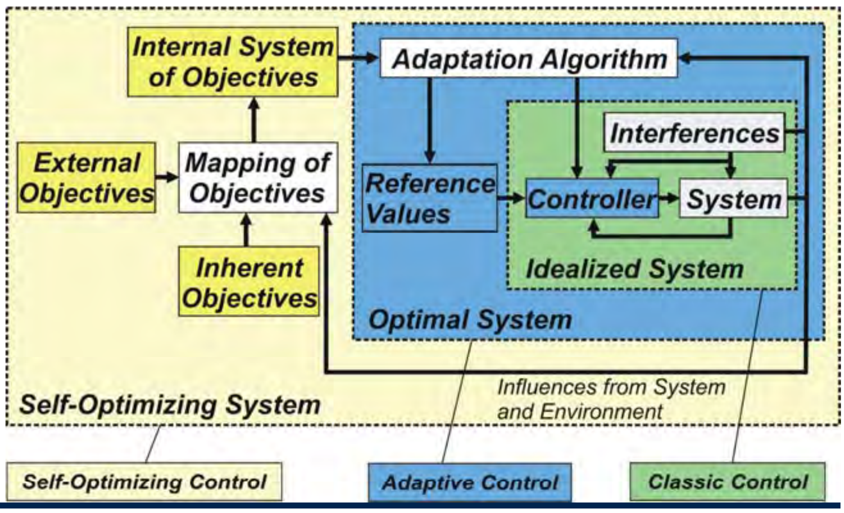


Self-Optimizing Systems

Self-Optimization offers Advanced Control of Mechatronic Systems

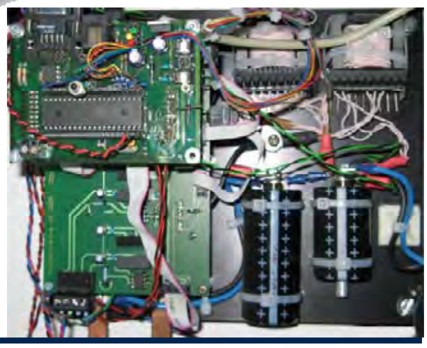
- Relevance of different objectives is adapted to varying operating conditions during runtime
- Exceeds adaptive control by adaptation of objectives, not only behavior

→ Ensures optimal system behavior even under changing surroundings and demands



Practical Students' Work on Electric Vehicles

- Design and assemble hardware
  - Power electronics (inverter etc.)
  - Electrical machines (IPMSM)
  - Hybrid energy storage
- Develop control software
  - Control of power electronics
  - Power management strategies
  - Communication via CAN-bus
- Platforms
  - CityEL electric vehicle with hybrid storage
  - Hybrid go-cart with power split drive train

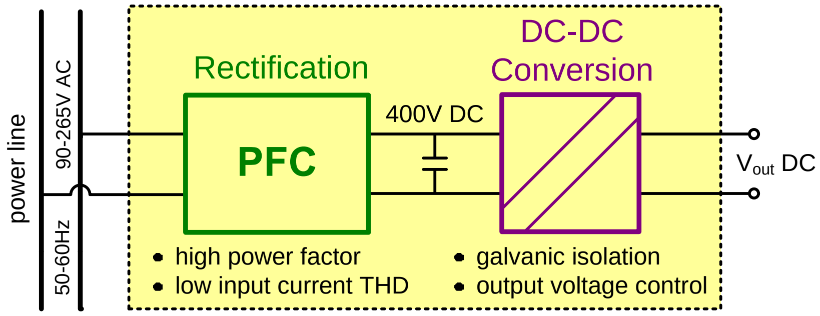


Power Electronics

Switched-Mode Power Supplies (SMPS)

DC Voltage Supplies

- Server and Telecom applications
  - V_{out} = 12V – 380V
  - P_{out} = 300W – 10kW



Digital Control

- Advanced control methods (adaptive, nonlinear, …)
- Feed-forward control
- Power management to improve efficiency, THD and PF especially at light load

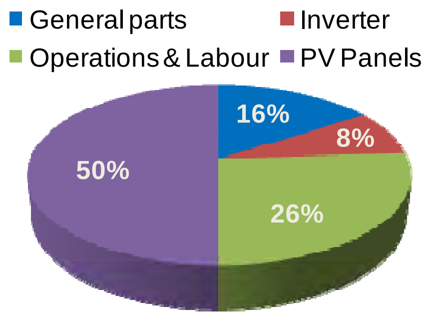
Efficiency Optimization of PFC and DC-DC Stage

- Advanced DC-DC topology, e.g. LLC resonant converter
- Multiphase PFC and DC-DC topologies
- Using digital control facilities

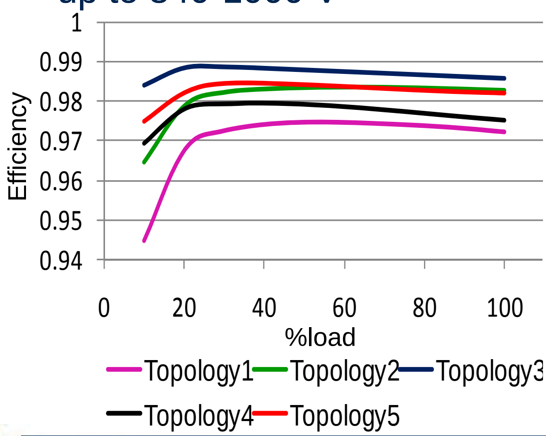
High Efficiency Commercial PV Inverter

Economics of Photovoltaic System

- Costs of inverter negligible (8%)
- 1% improvement in inverter efficiency
  → 80$/kW lesser initial costs & benefits on logistics (land costs, etc.)



Future Trend: Higher MPP voltages up to 840-1000 V



Project Scope

- Effects of higher voltages on low & medium voltage grid tied systems
- Develop marketable topology
  - Higher PV voltages
  - High efficiency
  - Low costs & size
  - High reliability

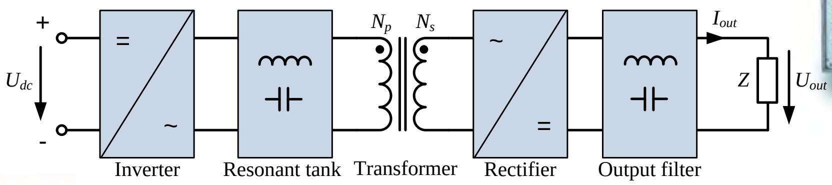
RPC-HVTS-DCS - Resonant Power Conversion

Research Topics:

- Modeling and control design for resonant operated DC-DC converter
- Multi-objective optimization environment for optimal converter design
- Bidirectional HV converter

Applications

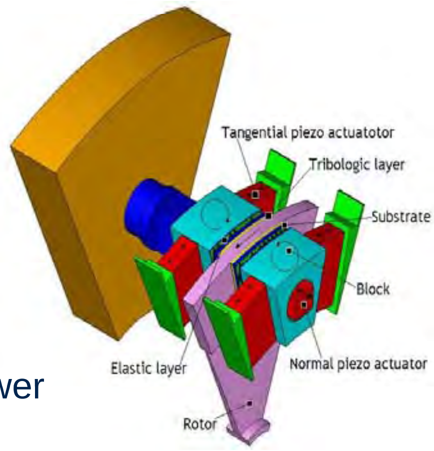
- High-dynamic DC-sources (DCS)
  - Higher dynamics, smaller outline
- Very low frequency HV test systems (HVTS)
  - Higher efficiency, smaller outline



Power Supply for Piezoelectric Actuators

Characteristics of piezoelectric actuators

- High force, small displacement
  - Capacitive characteristic
  - Operated at resonant frequency



Power supply for piezoelectric actuators

- 2-level or 3-level inverter topologies
- Compensation of the capacitive reactive power
- Reduction of THD with optimal modulation strategy
- Filter design at minimal volume and weight