Institut für
Antriebssysteme und
Leistungselektronik

Leibniz
Universität
Hannover

Role of Power Electronics and Drive Systems in Modern All-Electric and All-Digital Society

Prof. Dr.-Ing. Bernd Ponick

Gottfried Wilhelm Leibniz University Hannover

- Founded in 1831
- 9 Faculties
- 30.000 Students
- 340 Professors
- 3.000 Research Associates
- Member of German TU9

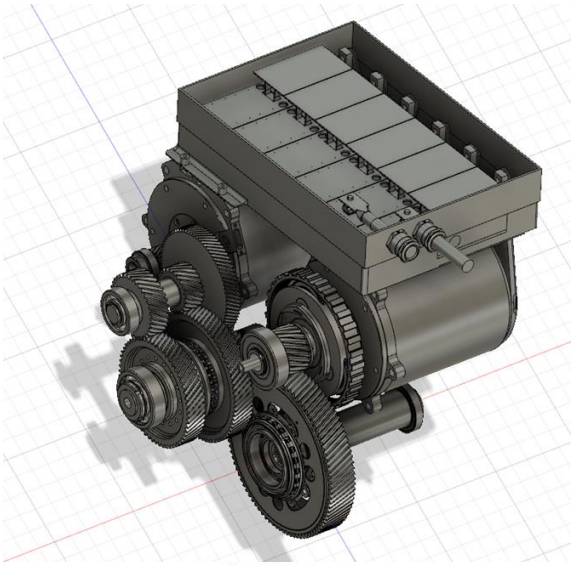
Institute for Drive Systems and Power Electronics

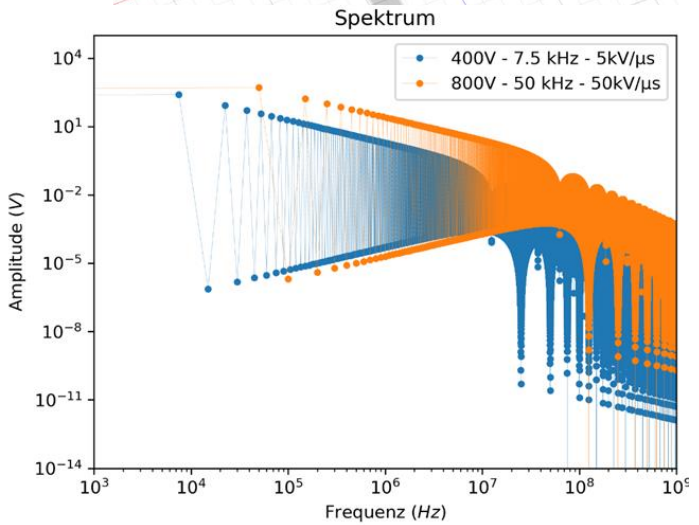
Team:

- 2 Full Professors
  (Axel Mertens, Bernd Ponick)
- 2 Junior Professors
- 2 Senior Engineers
- 50 Research Associates
- 6 Technical Staff
- 3 Office Staff

Outline

- Dominating global trends
- Challenges related to PEDS
- Trends in research governance
- Consequences for university research in engineering
- Open research questions
- Importance of cooperation





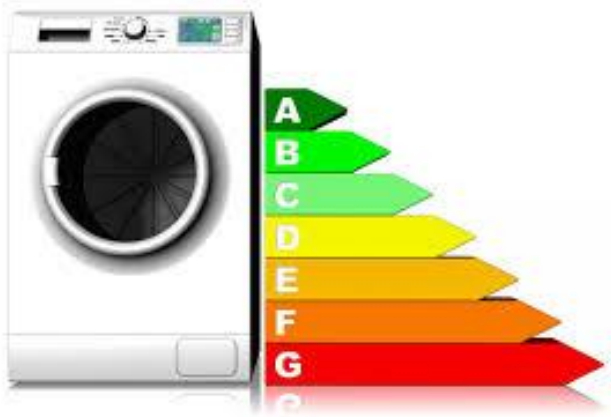
Dominating Global Trend

Consequences

Decarbonization of traffic and transportation

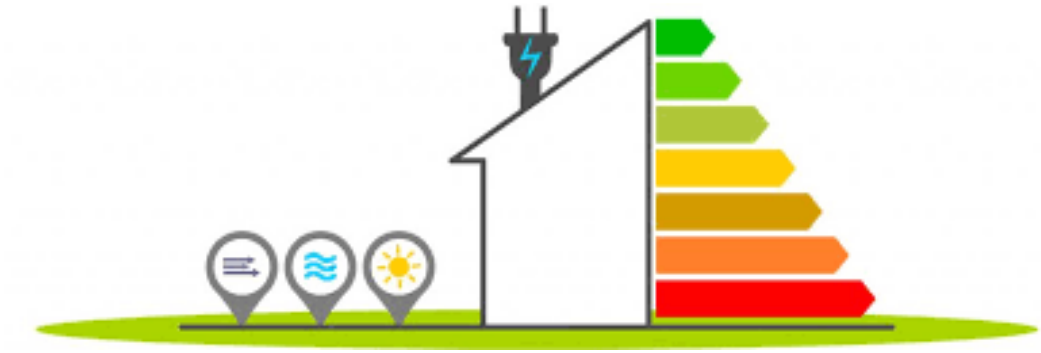
Decarbonization of industry
and energy supply

Consequences

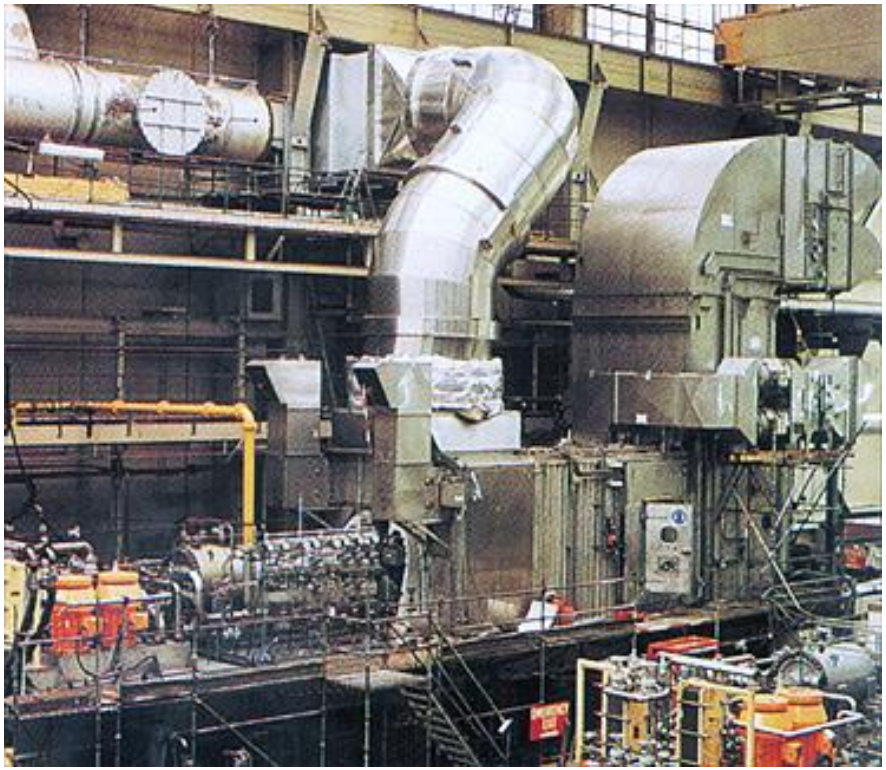


Improvement of energy efficiency

Less is more!?



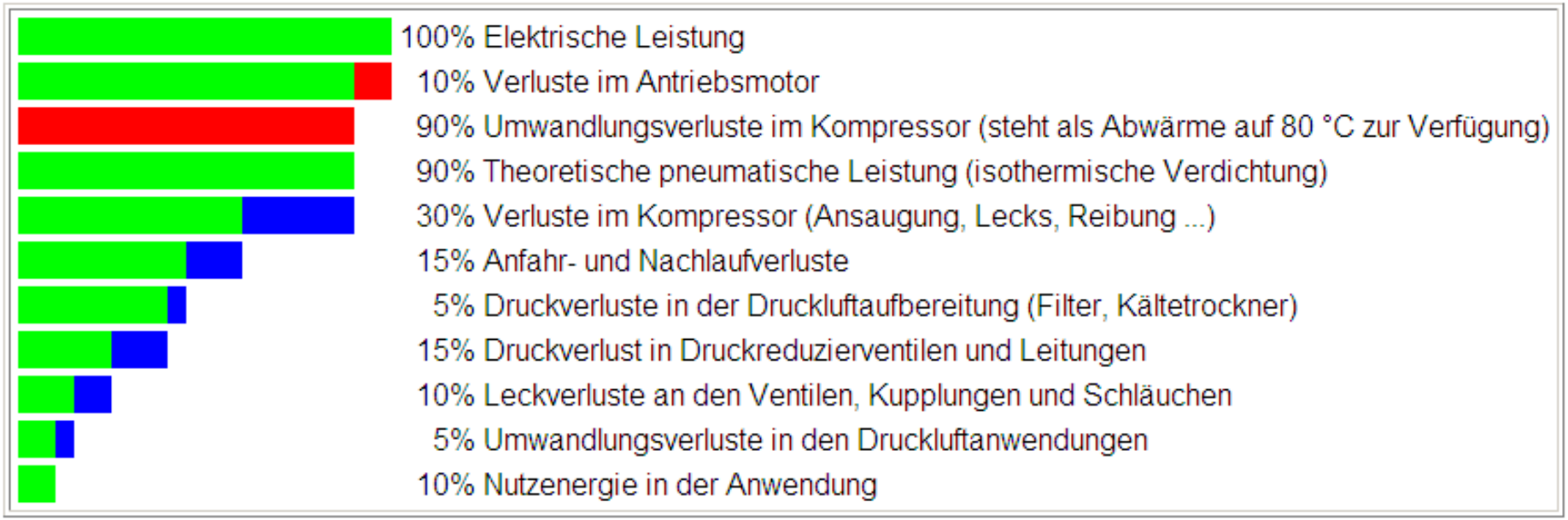
Example: Energy Savings by Replacing Gas Turbines



Industrial Gas Turbine,
Efficiency 25 ... 38%

Variable Speed Drive System for Compressor,
Efficiency > 96%

Example: Energy Savings by Replacing Pneumatics



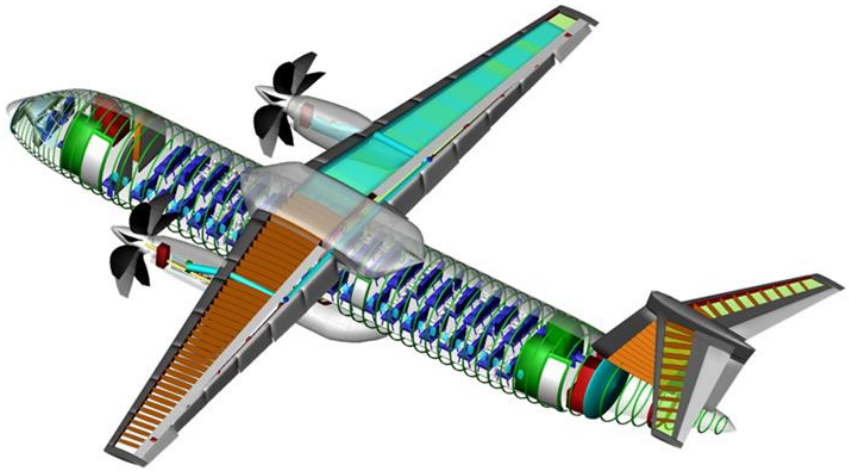
Quelle: Gloor, Energieeinsparungen bei Druckluftanlagen in der Schweiz; BfE 2000

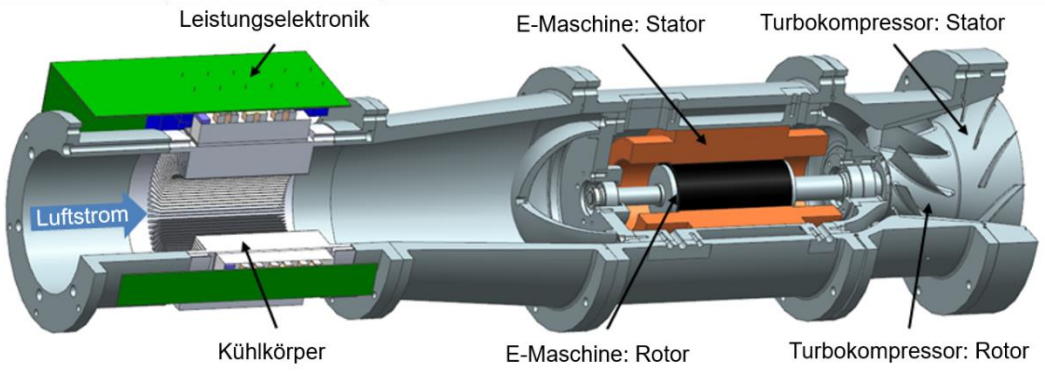
- System efficiency of pneumatics: 10%
- System efficiency of electric drive systems: 70 bis 90%
- Potential energy saving > 80%

With Respect to Efficient Use of Energy and Resources:
Is the All-Digital Society Threat or Chance?

PEDS is Key for Mastering Transformation Process

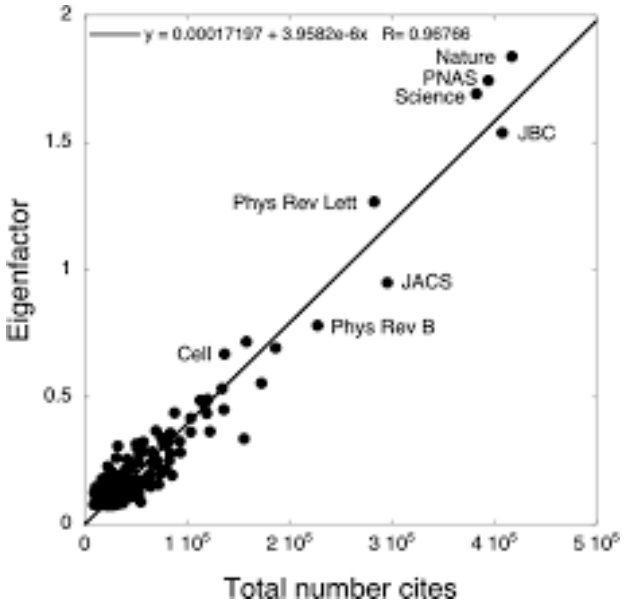
- Use of wind, solar and hydro energy
- Control of energy transmission
- Energy storage systems
- Replacing mechanical drivers
- Efficient energy conversion

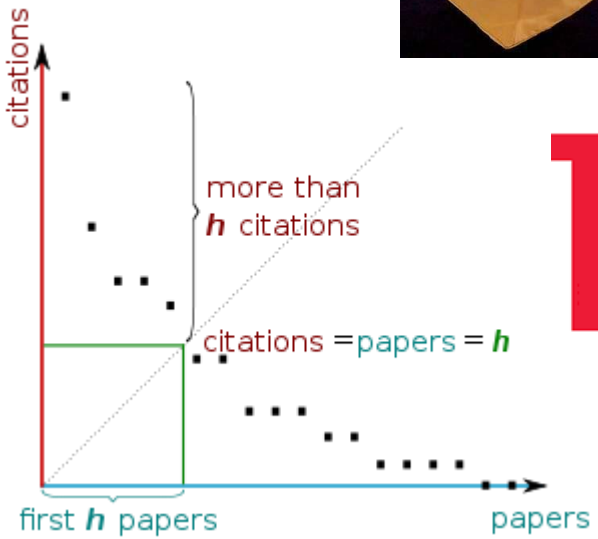




Trends in Research Governance

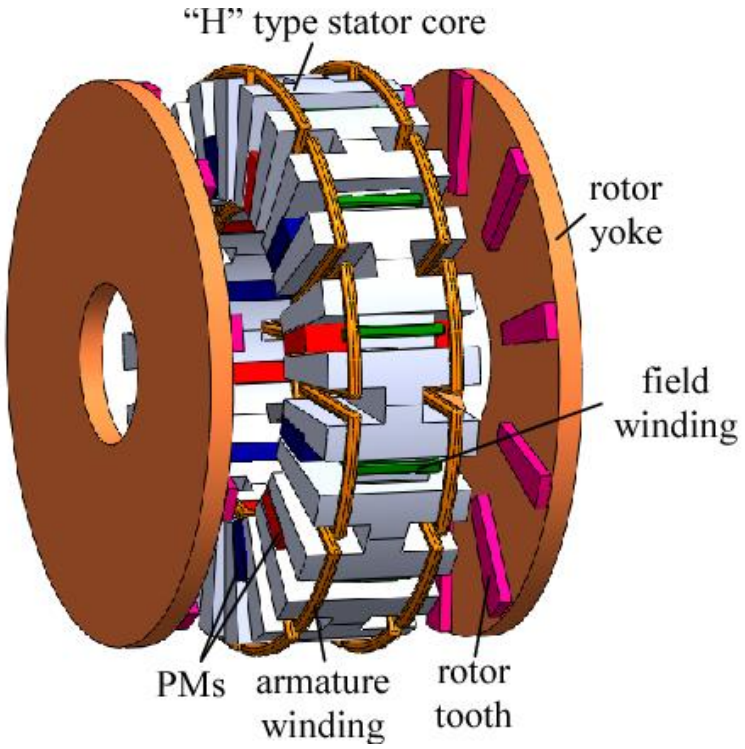
- Focus on publications
- Focus on rankings and metrics
- Tenure track careers

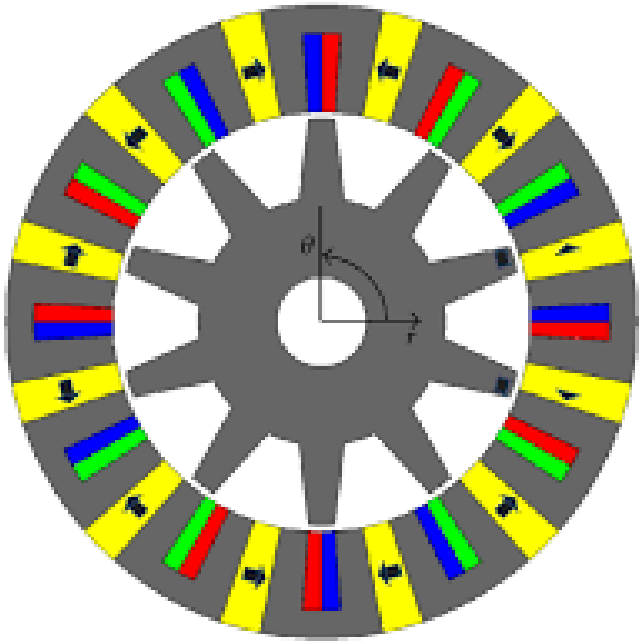




THE WORLD UNIVERSITY RANKINGS

Consequences for Research in Engineering

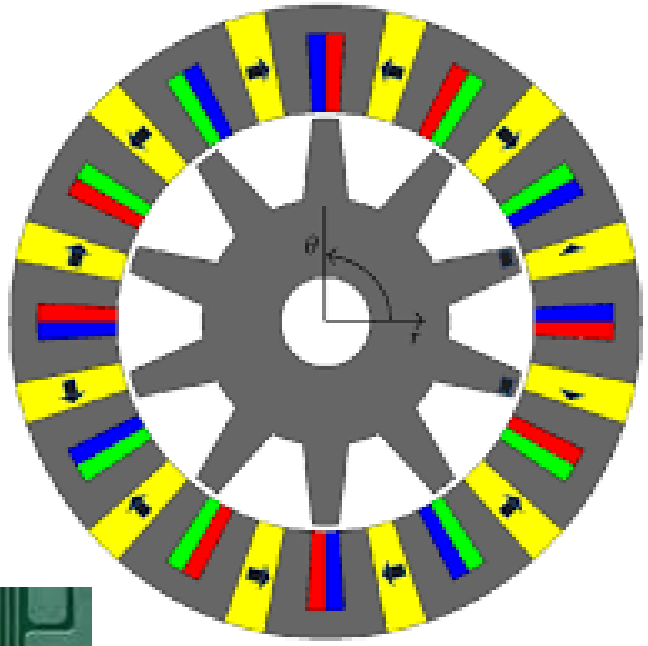


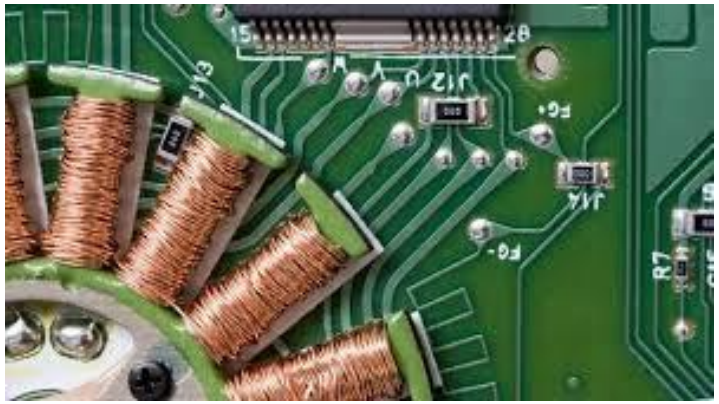


- Great for producing publishable results
- Without any practical relevance

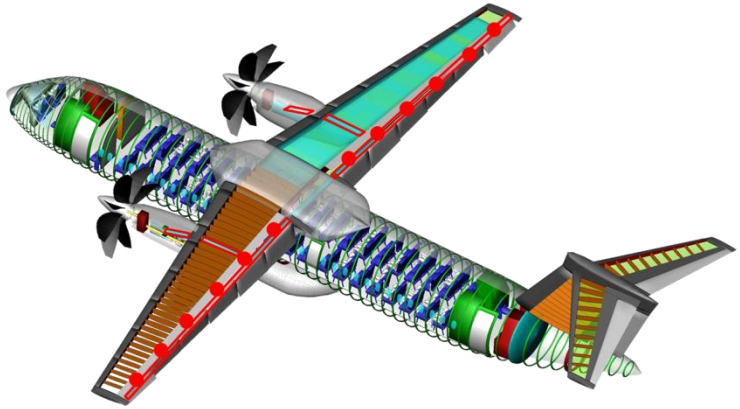
Relevant Aspects

- Rigidity of mechanical setup
- NVH behavior
- Assembly process
- Tolerances
- Cooling
- EMC
- Robustness
- Simplicity
- Cost
- ...



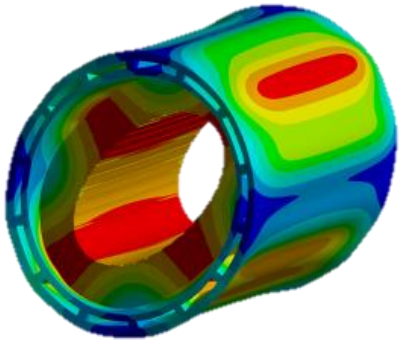


Challenges in PEDS



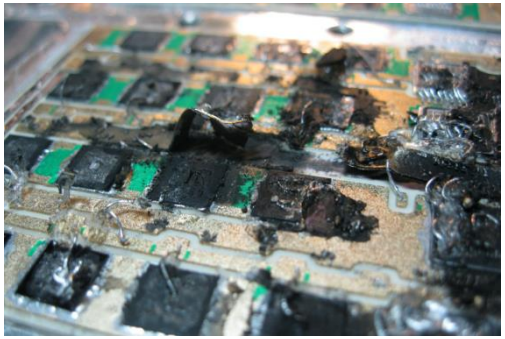
Weight and efficiency sensitive applications

Regenerative energy

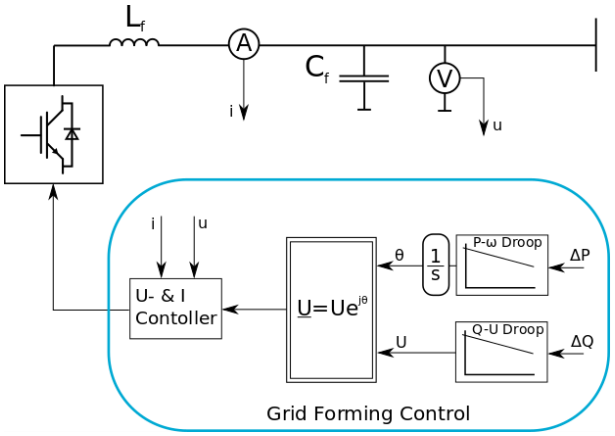


Mastering NVH

HF side effects



Reliability



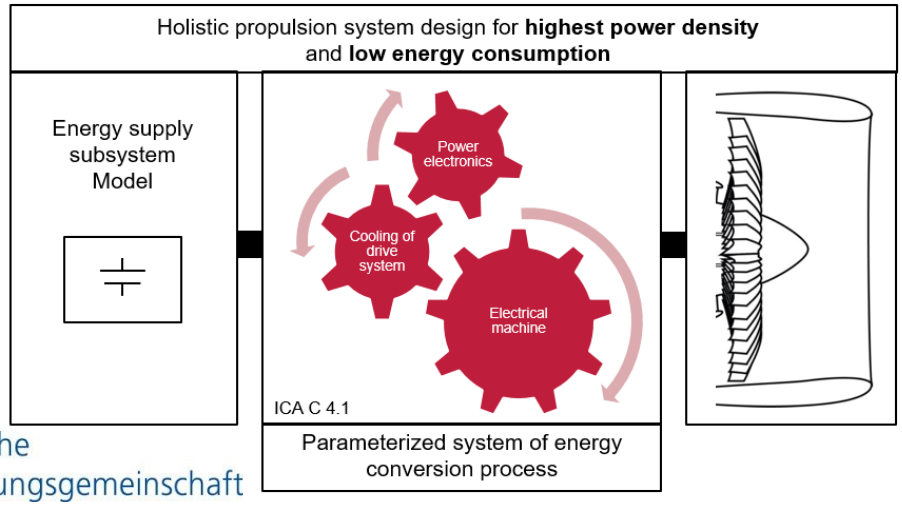
Grid stability and control

SE²A – Sustainable and Energy-Efficient Aviation

SE²A

Electric Propulsion Drive Concepts for Future Electrified Aircraft

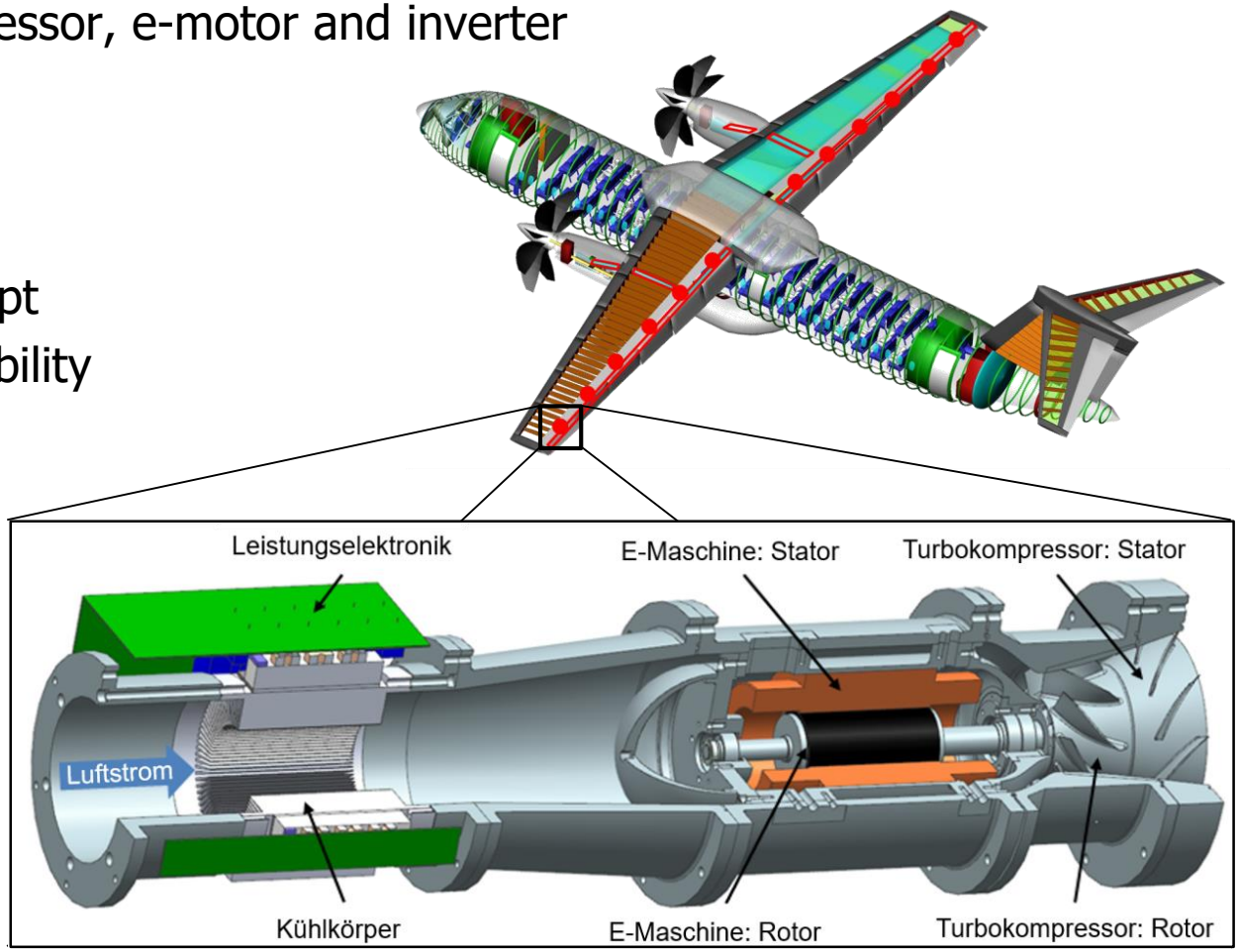
- Requirements analysis and concept studies
- Cooling system design and thermal modelling
- Use of super-conductivity
- Cold power electronics
- Radiation resistant components
- Decentralised vs. central electronic power conversion structure
- Requirement-oriented design of e-motors and system simulation
- Comprehensive evaluation of the overall drive system



DFG Deutsche Forschungsgemeinschaft

Active High-lift System for Future Aviation

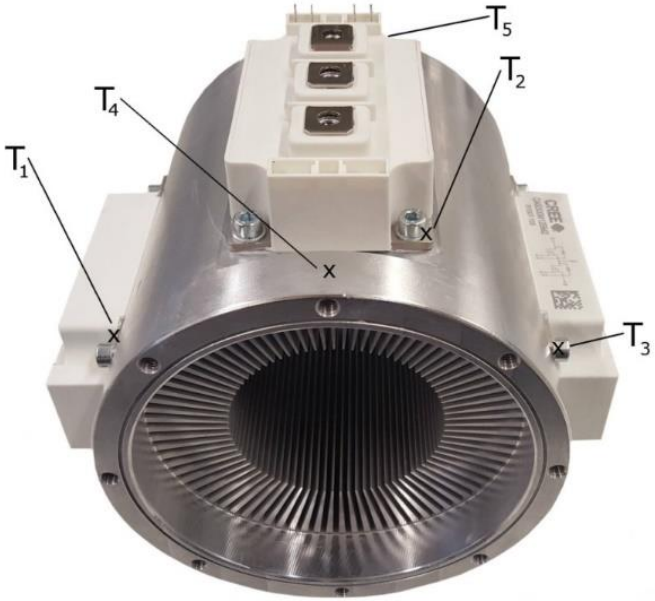
- Integration of compressor, e-motor and inverter
- High speed
- High power density
- High efficiency
- Simple cooling concept
- Robustness and reliability

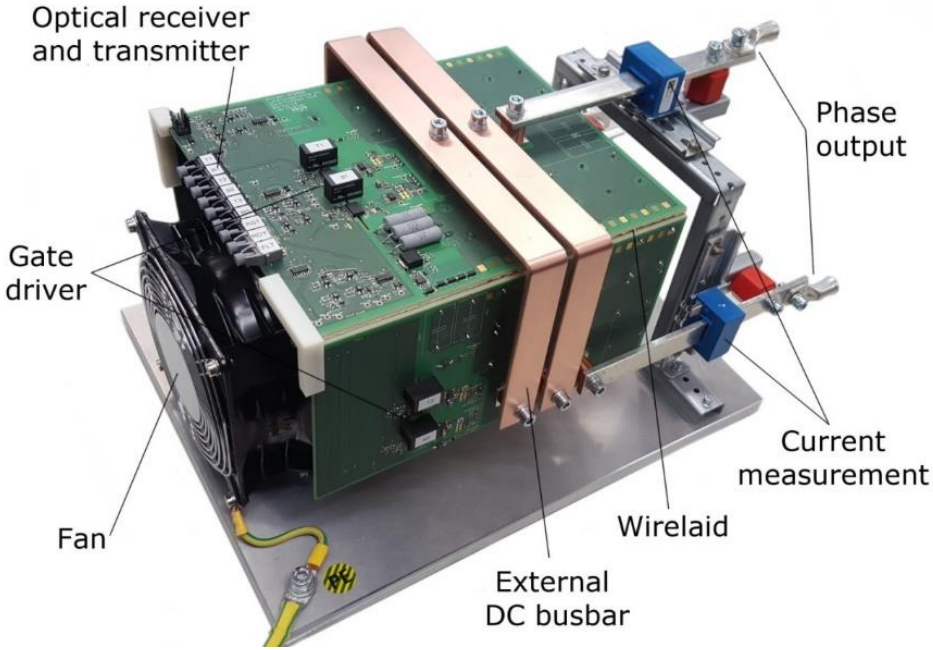


DFG Deutsche Forschungsgemeinschaft

SiC Inverter for High-lift System

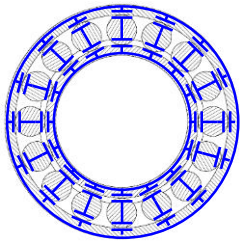
- Rated power > 100 kVA, SiC MOSFET modules 300A / 1200 V
- Power losses 600 W per module only, efficiency up to 99 %
- Air-cooled, 11 kW/l (box volume), potential improvement up to >20 kW/l
- But: challenging HF effects due to voltage gradient up to 100 kV/µs

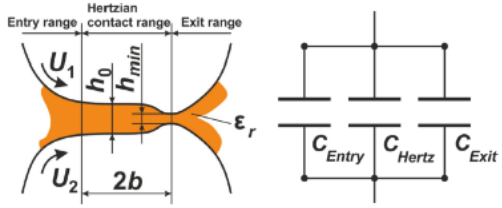


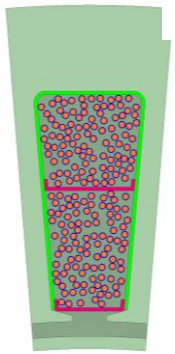


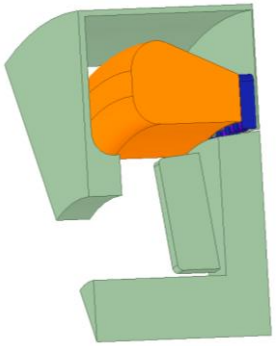
HF Side Effects due to High Voltage Gradient: Bearing Currents, Stress of Main Insulation and EMC

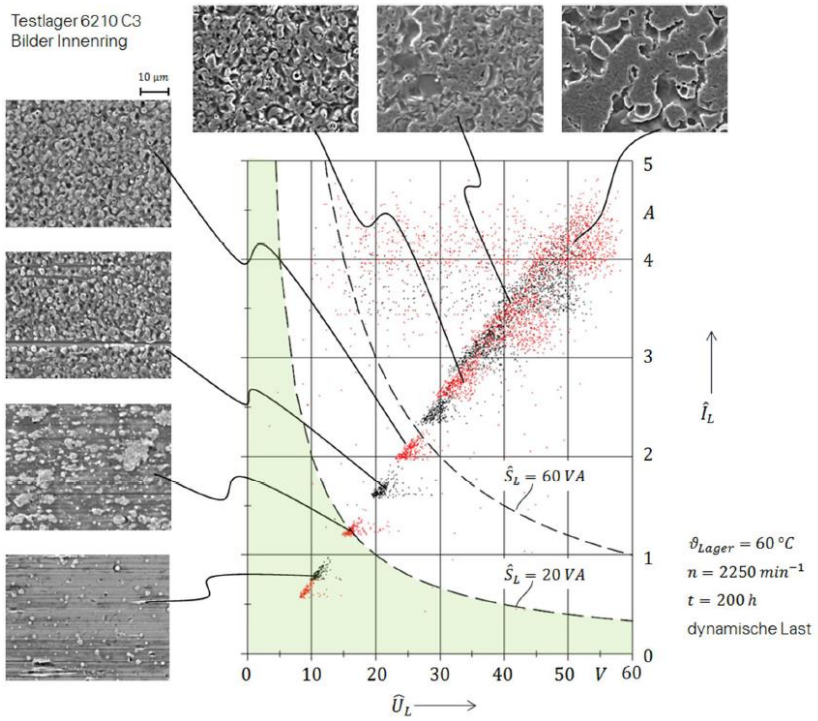
- HF-modelling of e-machines
- Prediction of bearing currents and deterioration
- HF parameter identifikation
- Model validation by measurements

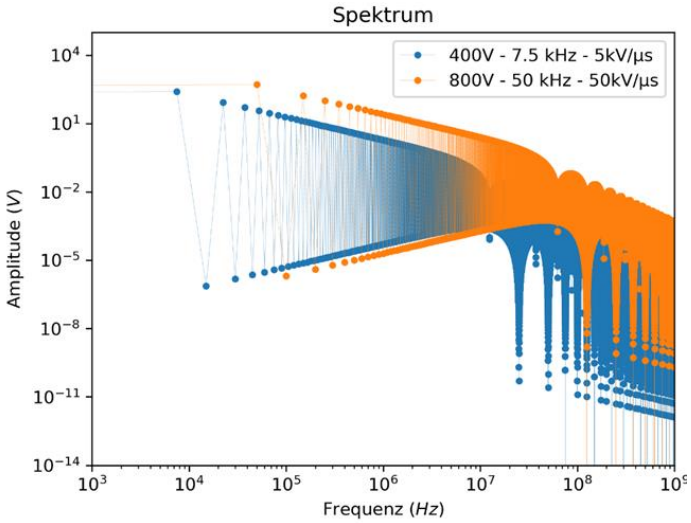




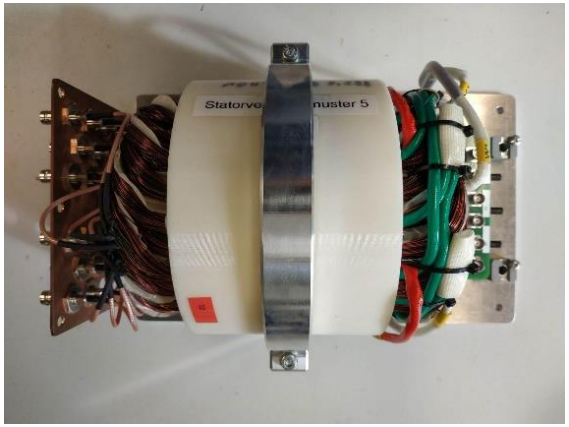


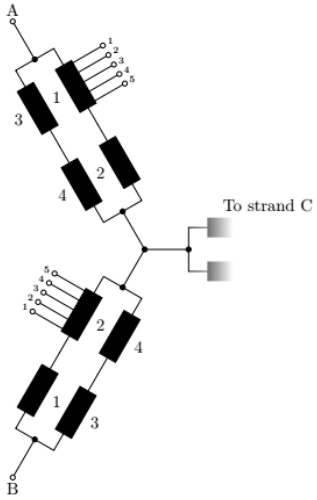


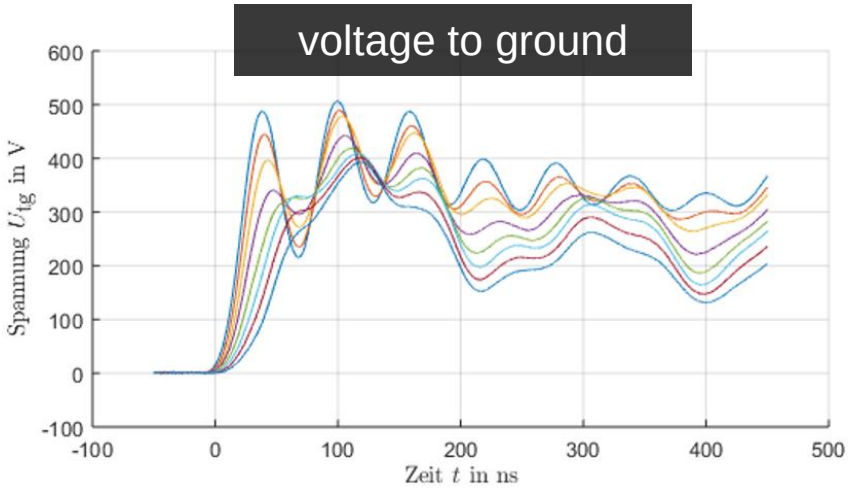


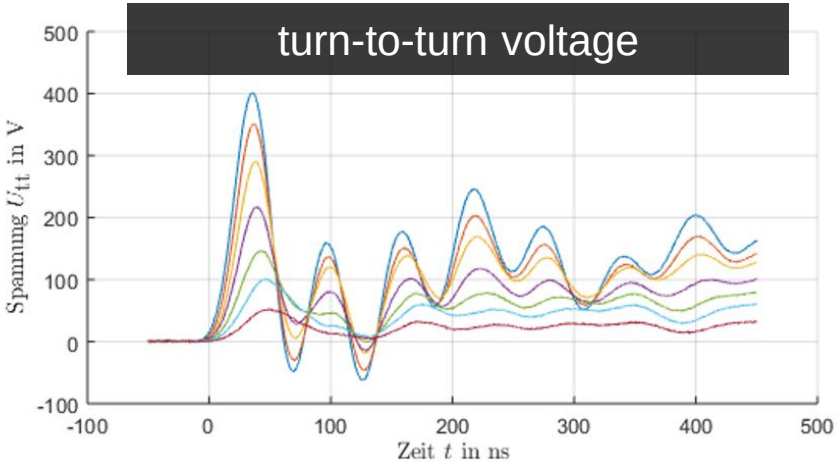


Insulation Stress due to High Voltage Gradients









- HF-modeling of stator winding
- Identification of model parameters
- Model validation

Piloting High-Wind Energy Harvesting

Sky Power 100

- Design and investigation of drive train (electric machine and power electronics) for an average power of 1 MW
- Realisition of a fully automated 100 kW pilot plant
- Investigation of the interaction of several plants in combination
- Investigation of preferable exterior rotor generator principle
- Low noise emission

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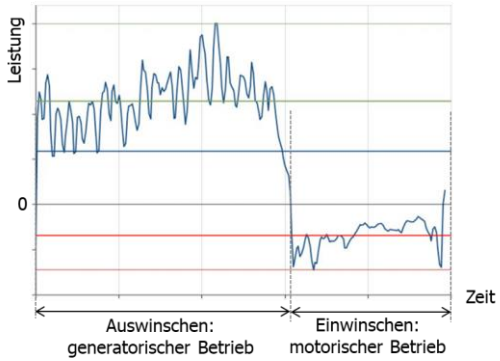
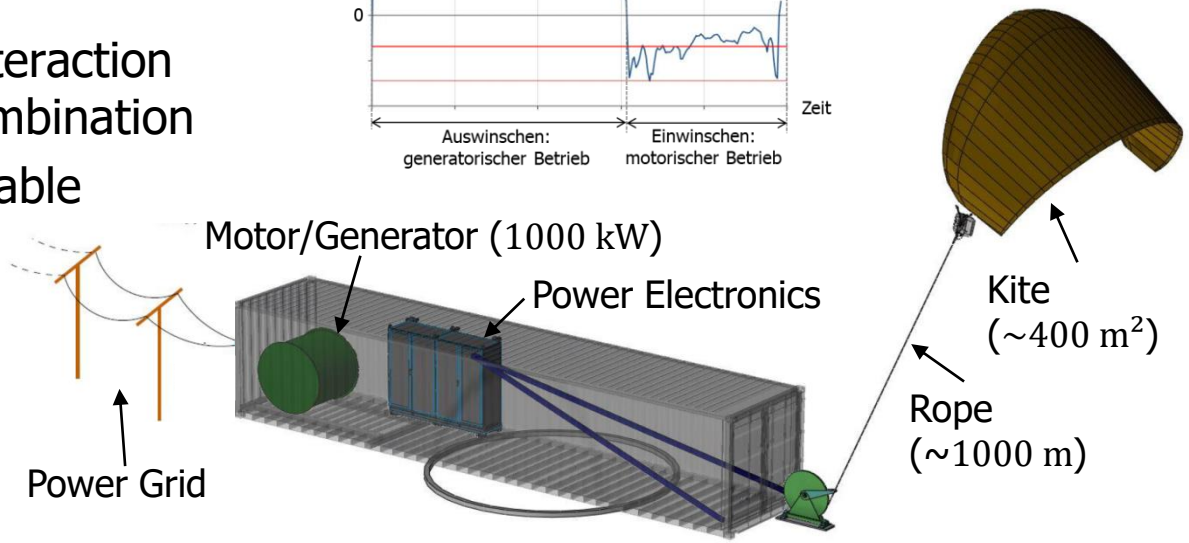
SkySails POWER

EWE

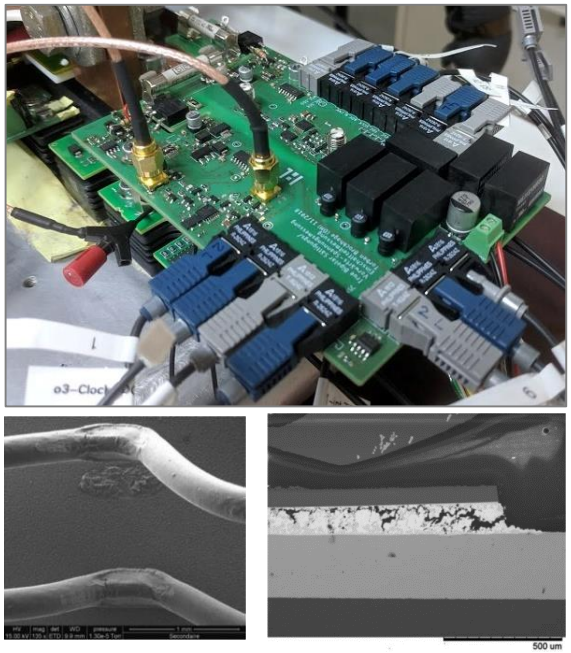
EnBW

Projektträger Jülich Forschungszentrum Jülich

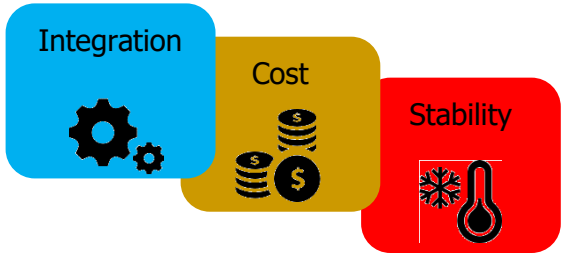


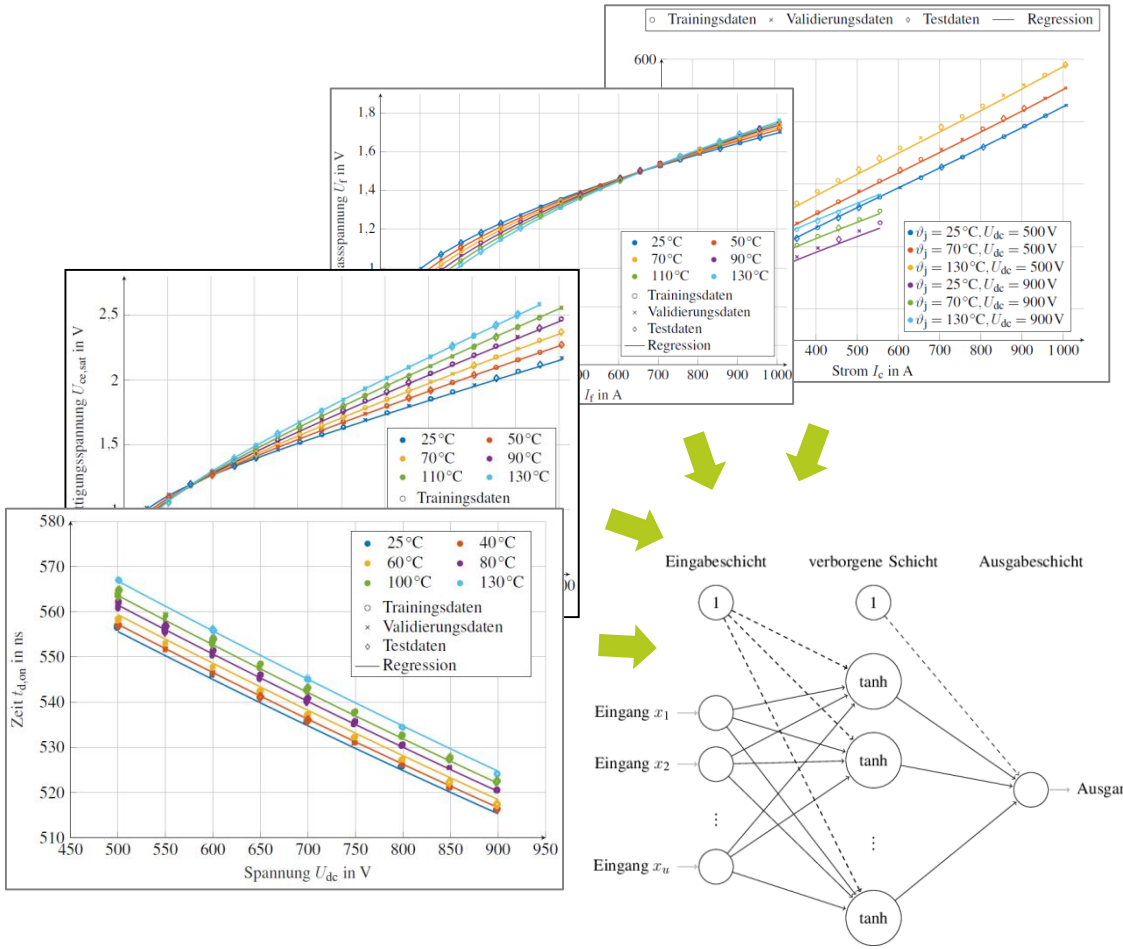


State Estimation / Condition Monitoring of PE



[1]

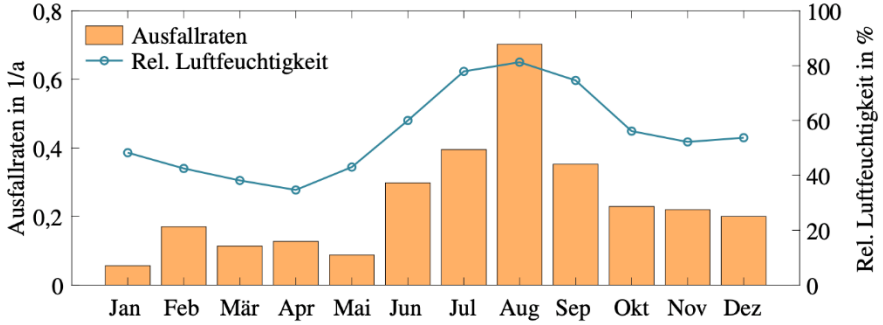




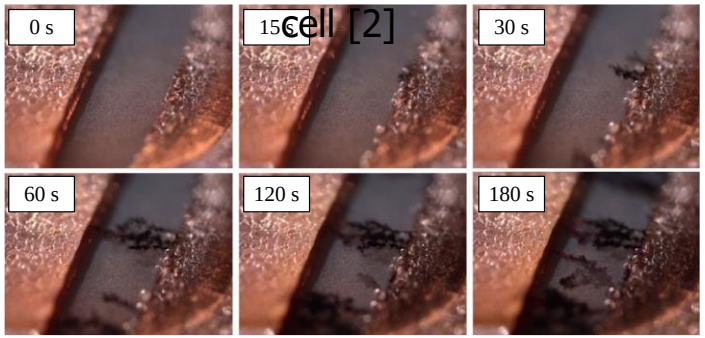
[1] Zuverlässige Leistungselektronik für Windenergieanlagen
Abschlussbericht zum Fraunhofer-Innovationscluster Leistungselektronik für regenerative Energieversorgung, Fraunhofer IWES, Stuttgart: Fraunhofer Verlag 2018, ISBN: 978-3-8396-1326-9 http://publica.fraunhofer.de/documents/N-491205.html

Humidity in Power Electronics - ReCoWind

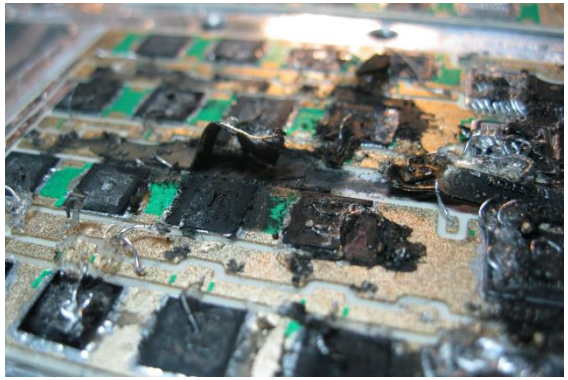
Failure rates of phase modules of WEA and relative humidity in India [1]



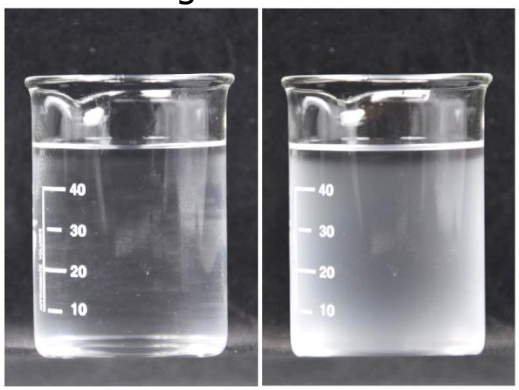
Degradation mechanism: electrochemical migration in galvanic cell [2]



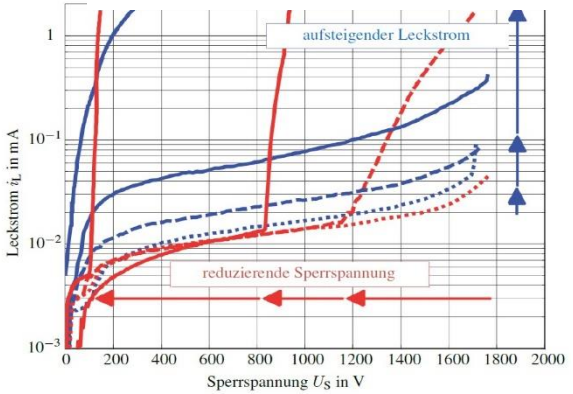
Destroyed phase module



Modeling of condensation



Reduced reverse voltage and leakage current [3]



[1] Bartschat et al.: *Zuverlässige Leistungselektronik für Windenergieanlagen: Abschlussbericht zum Fraunhofer-Innovationscluster Leistungselektronik für regenerative Energieversorgung* Stuttgart: Fraunhofer Verlag, 2018

[2] Bayer et al.: Electrochemical Corrosion on Ceramic Substrates for Power Electronics - Causes, Phenomenological Description, and Outlook. In: *CIPS 2018; 10th International Conference on Integrated Power Electronics Systems*, 2018

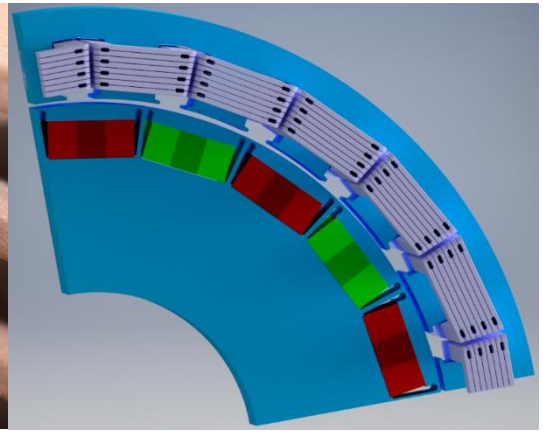
[3] Zorn et al.: Temperature–humidity–bias testing on insulated-gate bipolartransistor modules – failure modes and acceleration due to high voltage. In: IET Power Electronics 8 (2015), Nr. 12, S. 2329–2335

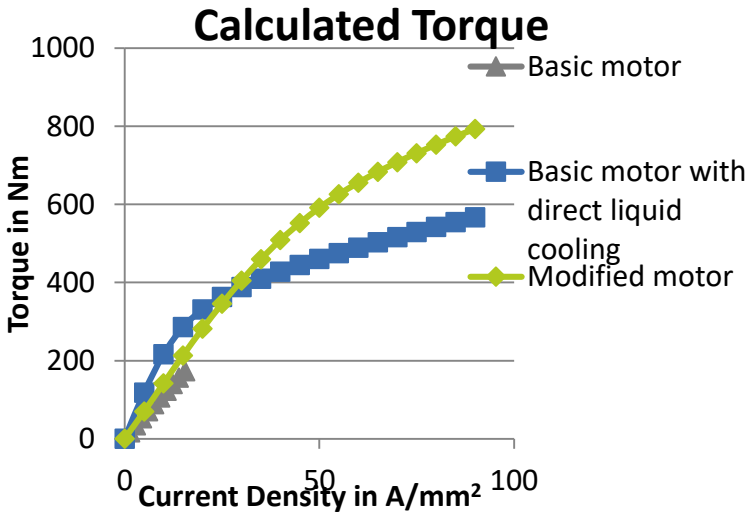
Bundesministerium für Wirtschaft und Energie

Extreme Torque Density by Direct Liquid Cooling

Direct liquid cooling of stator winding

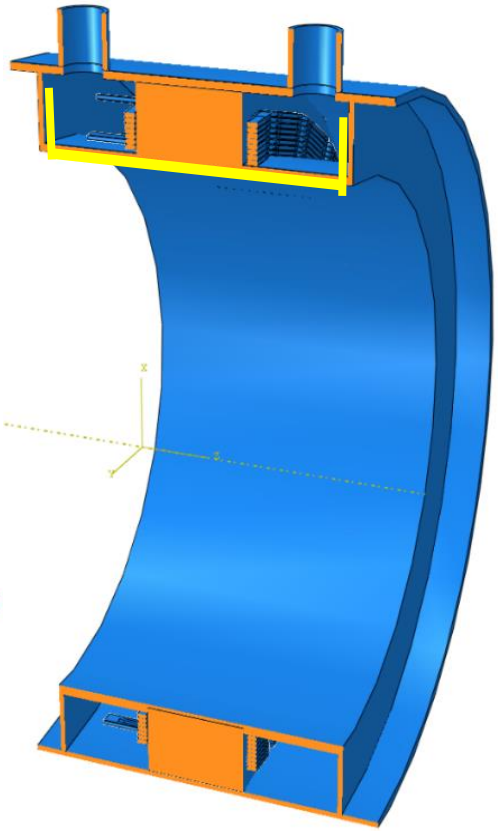
- cooling cannel integrated into each conductor
- current density up to 100 A/mm² feasible compared to 3 ... 5 A/mm² in case of air cooling and 12 A/mm² in case of water jacket
- But: Loss density increases with current density squared

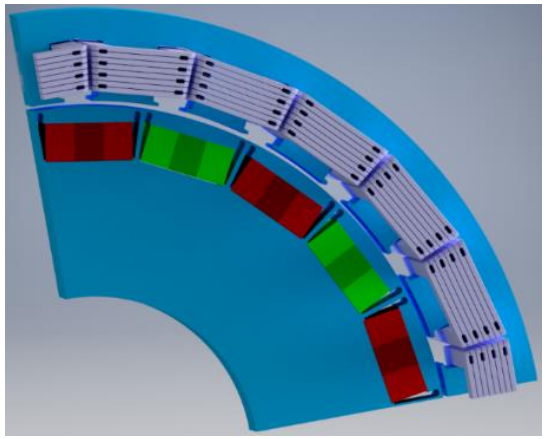


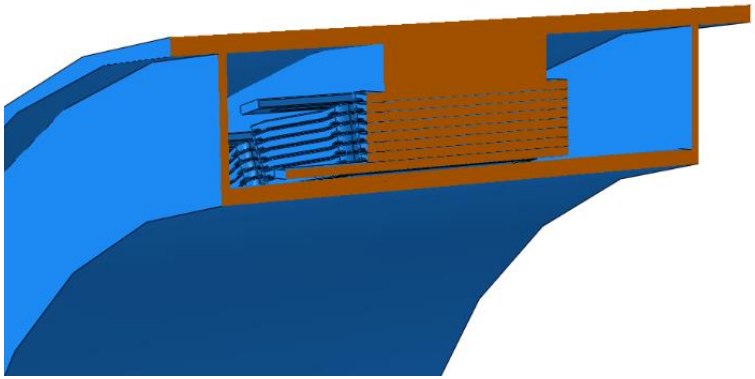


Extreme Torque Density by Direct Liquid Cooling

- Torque density increased by factor 5 compared to torque-motor with water jacket
- Good compromise at 60 A/mm²
- Low pressure drop due to parallel cooling channels
- New design rules for magnetic circuit required
- Potential to replace hydraulic motors

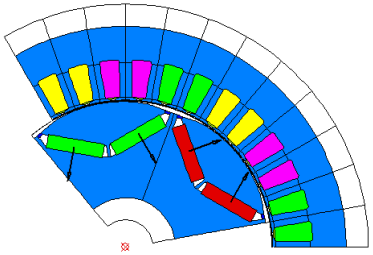


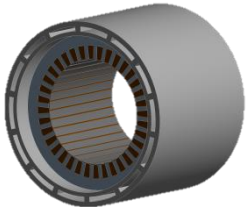


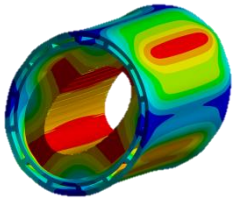


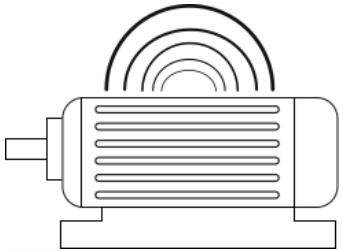
Time-Efficient NVH Prediction of Drive Systems

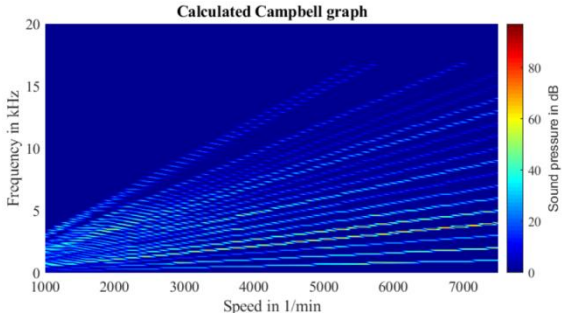
- Prediction of force density at stator bore from magnetostatic 2D FEA or analytics
- Reduction of structural-dynamic FEA model to modal transfer function
- Modal superposition requires 0,1 % of computation time compared to FEA
- Sound-pressure level via analytical models
- NVH prediction for complete operation range within minutes
- Online control of noise emission by inverter feasible

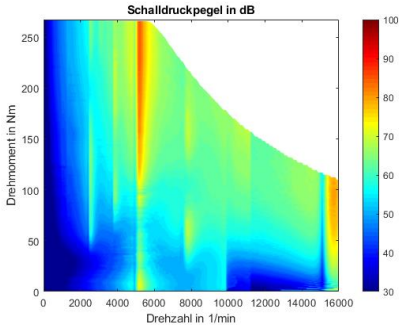








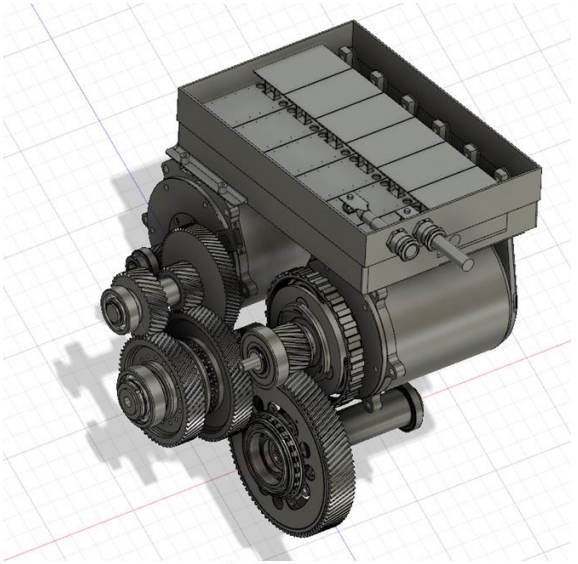


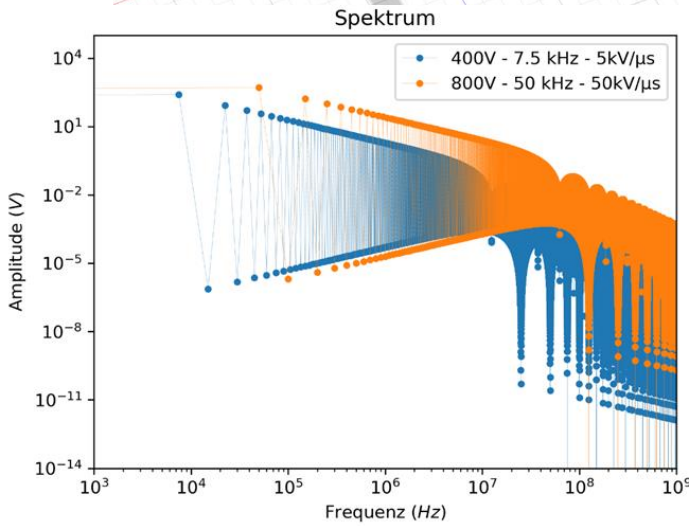


Prediction of force density → Modal superposition → Sound-pressure level

Conclusion

- Further increasing importance of PEDS
- Many challenges
  - New applications
  - Substitution of mechanical drivers
  - HF side effects due to UWBG power electronics
  - Reliability, monitoring, diagnosis
  - Grid stability and control
  - High power density and torque density
  - Low losses and NVH
  - Additive manufacturing for functional integrateon
- Cooperation of experts from different disciplines required
- Best results in case these experts share the same coffee machine





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