Fraunhofer IZM

Fraunhofer Institute for Reliability and Microintegration IZM

Electronic Packaging Days 2025

Dr. Stefan Wagner

Challenges of Reliable Power Electronics

Overcoming obstacles in efficient electronic power systems

Technological challenges

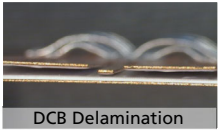
Stressors and Boundary Conditions

Thermal and Mechanical Stress

- Thermal cycles and power cycling cause material fatigue and structural changes in electronic components.

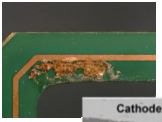
Electrical Stress Factors

- Electrical loads such as short-circuit resistance, overvoltages, and partial discharges increase component demands.



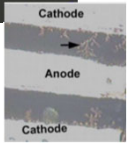
Environmental Influences

- Humidity, hygroscopy, and corrosion significantly affect the long-term stability of electronic parts.



Design Uncertainties and Modeling

- Material and manufacturing variations create design uncertainties needing early integration in simulations.

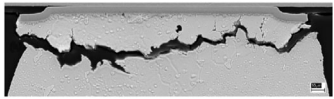


Regulations by (future) legislation – Circular Economy

- Future regulations by legislation will impose new conditions regarding recyclability, repairability, and reuse on new developments (EcoReliability).

Technological challenges

Failure mechanisms and components



Failure Mechanisms in Assembly

- Fatigue in sinter and solder joints, delamination, and cracking in wire and clip bonds affect reliability.

Material degradation

- The change in material parameters due to the aging of materials (such as thermo-oxidation of epoxies) can result in additional failure mechanisms.

Device-Specific Degradations

- SiC-MOSFETs face gate oxide degradation and body diode wear, while GaN-HEMTs suffer from dynamic RDS(on) and trapping.

EMC and Crosstalk Challenges

- High switching speeds cause electromagnetic interference and crosstalk, requiring co-design of layout and packaging.

Advanced Failure Analysis

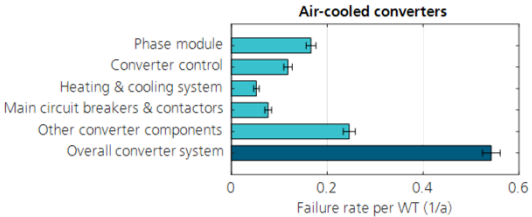
- Analytical methods like FIB-SEM, EBSD, and X-ray CT help identify and address these failure mechanisms precisely.

Failure data analysis wind turbines

Failure components

Main failure components:

- Phase module components (IGBT modules, driver boards, DC link capacitors and busbars)
- Inverter control



Source: Funded project in the PREPARE program of Fraunhofer-Gesellschaft
title: Reliable Power Converters for Renewables (power4re)

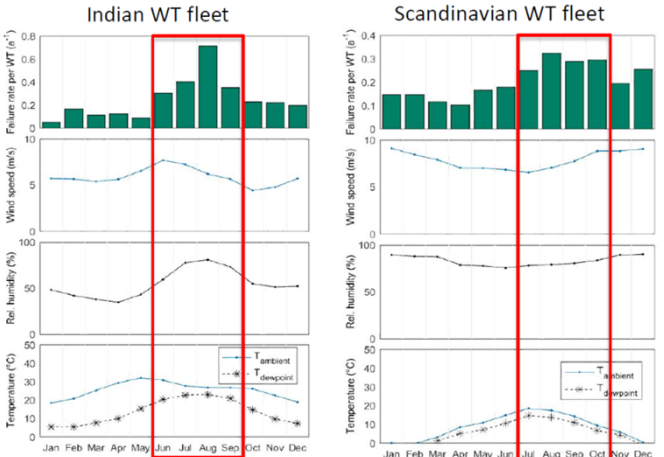
Wind turbine downtime

Seasonal failure patterns, correlation ambient conditions

Clusters of phase-module failures in humid seasons

Points to humidity as a key driver of converter failure in WT

- Humidity has a significant effect
- Phase-module failure rate doubles with each 5 g/m³ higher mean ambient absolute humidity



K. Fischer et al., "Reliability of Power Converters in Wind Turbines: Exploratory Analysis of Failure an Operating Data from a Worldwide Turbine Fleet", IEEE Transactions on Power Electronics 34(7), pp. 6332-6344, 2019

Failure Analysis and Case Studies

Failure Analysis as a Development Tool - Case Studies from Practice

Advanced Failure Analysis Methods

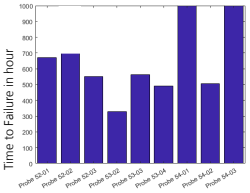
- Non-destructive and analytical techniques like X-ray CT, SAM, FIB-SEM identify root causes in electronics.

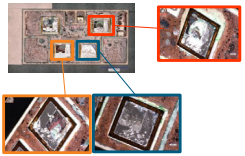
Closed-Loop Development Process

- Combining design, simulation, processing, testing and failure analysis enables continuous product improvement.

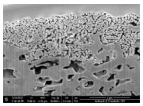
Design-for-Reliability Integration

- Failure analysis results guide design rules and test profiles, shortening development cycles and improving quality.





Substrate level investigation



KorSikA – Corrosion-resistant sintered joint technology for applications at risk of corrosion

problem definition: Corrosion of Ag Sinter Layers under Maritime Conditions
Goal: Development of Corrosion Prevention Strategies
solution approach:

- Production of samples (Ag Sinter Layers)
- Analysis (Electrochemical / Optical) of Corrosion Properties
- Analysis of Inhibitors for Corrosion Prevention
- Investigation of Various Material Combinations at Substrate and Module Level

Bundesministerium für Bildung und Forschung

Methods for Lifetime Prediction

Testing Procedures and Modeling

Accelerated Testing Methods

- Various methods like power cycling, temperature cycles, H3TRB, and high-voltage isolation tests evaluate electronic lifespan.

Reliability Modeling

- Models such as Arrhenius and Coffin-Manson are adapted to real mission profiles for accurate analysis

Data Calibration and Uncertainty

- Calibration using test bench and field data enhances model precision and supports robust design decisions

Design Optimization

- Combining test data and simulations enables early detection of weaknesses and targeted design improvements

Methods for Lifetime Prediction

Simulation and Digital Twins

Finite Element Method & Co-Simulations

- FEM and electro-thermo-mechanical co-simulations enable comprehensive reliability assessment through virtual experiments

Holistic Multi-Effect Analysis

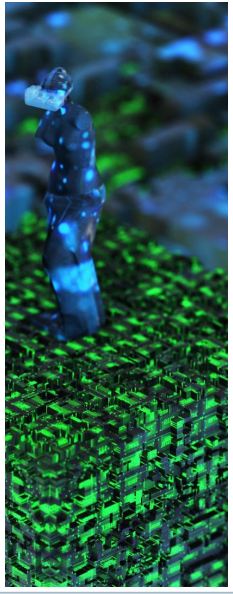
- Coupling thermal, mechanical, and electrical effects allows integrated analysis of junction-to-case and board behavior

Digital Twins & Design Iterations

- Digital twins support iterative design and development by providing virtual test protocols and damage KPIs

Process Integration Benefits

- Integrating simulations improves predictability, reduces field failures, and enhances communication across teams



Design-for-Reliability and Cooperation

Early Mission Profile Consideration
- Integrate real data-based mission profiles early in design to improve power electronics reliability sustainably

Standardized Testing & Models
- Implement application-specific test programs beyond JEDEC standards and couple models with test setups for traceability

Cross-Functional Collaboration
- Close cooperation between design, packaging, and lab teams enables early issue detection and resolution for reliability

System Reliability Assessment Group (and the IZM) Support & Engagement
- SRA Group offers reliability assessments, simulations, and failure analysis

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Thank you for your attention