Towards increased reliability of power converters in wind turbines

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E/E Systems for Wind Turbines
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Short profile of Fraunhofer IWES Northwest

Head of the institute:	Prof. Dr. Andreas Reuter
Research spectrum:	Wind energy from material development to grid integration
Overall budget 2013:	around 14 million €
Staff:	150 employees
Previous investments in the establishment of the institute:	€ 50 million

Forschungsverbund Windenergie

Strategic Association with ForWind and the German Aerospace Center (DLR)

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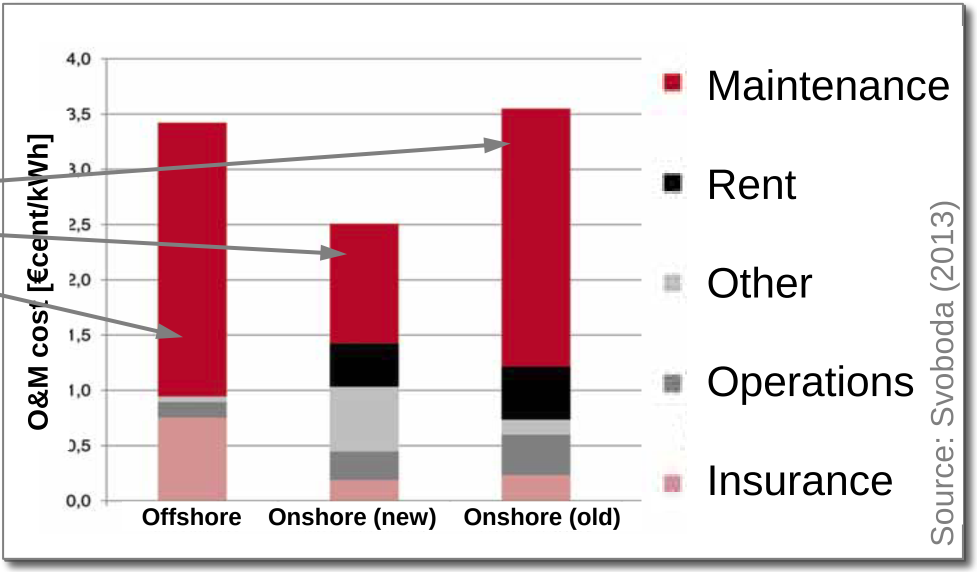
Reliability is key

- Operation and Maintenance (O&M) cost sums up to ~1/3 of the wind turbine life cycle cost (LCC)
- Large portion of O&M cost: Maintenance cost (service and repair)
- In addition: opportunity cost due to unavailability



Reliability is among the key factors for a further COE reduction

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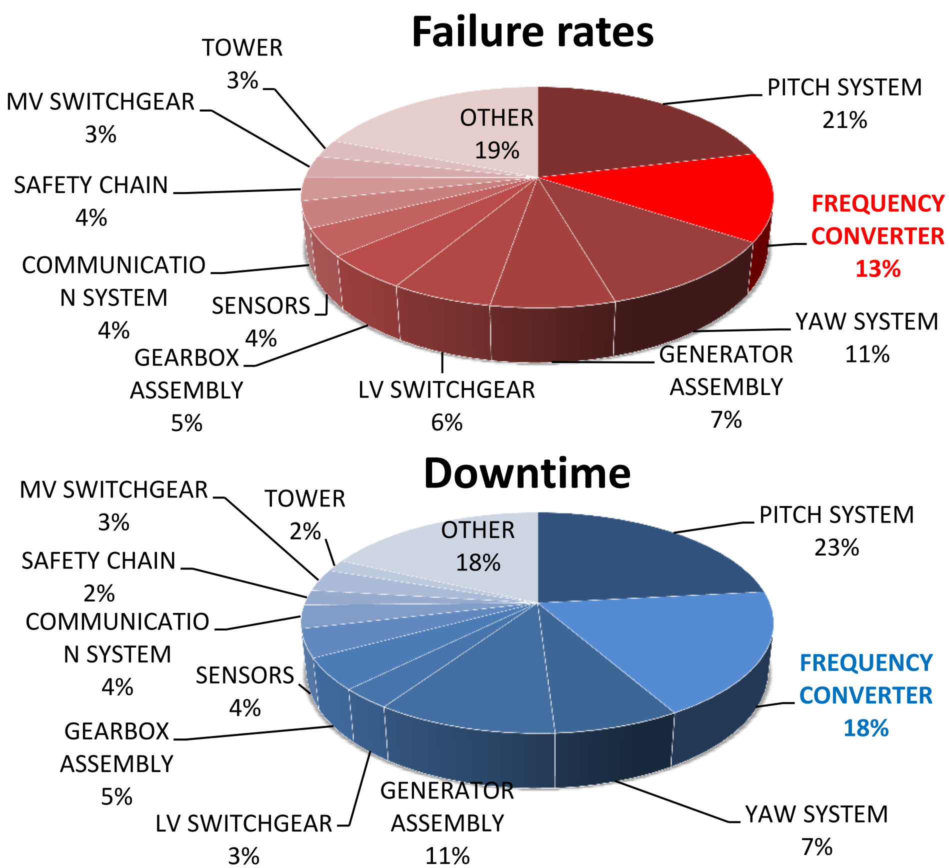
Challenge: Power-converter reliability

Reliability study for variable-speed wind turbines (RELIAWIND project, 2008-2011):



- High failure rates of power converters cause considerable maintenance cost and production loss
- Impact on turbine availability offshore more severe than onshore
- Problem concerns virtually all OEMs and wind-turbine topologies
- Failure causes are presently mostly unknown
- Urgent need for solutions

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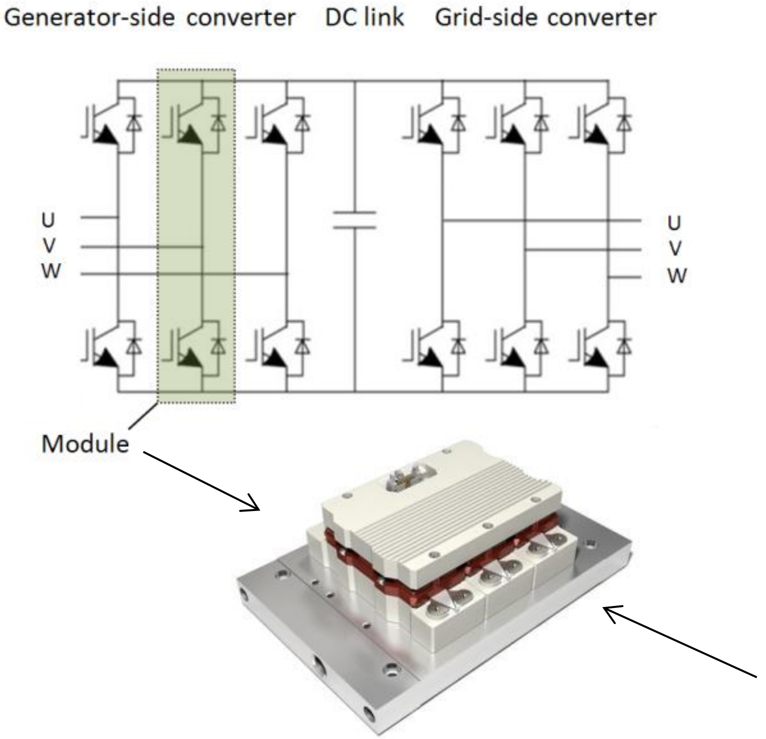
Project "Investigation of converter failure in wind turbines" (CONFAIL)

- Participants:
  - T. Thiringer, R. Karlsson, Chalmers Univ. of Techn., Göteborg
  - T. Stalin, Vattenfall Wind Power, Stockholm
  - J. Wenske, Fraunhofer IWES, Bremerhaven
  - H. Zelaya, ABB Corporate Research, Västerås
  - H. Ramberg, Volvo Car Corporation, Göteborg
  - G. Wetter, Swerea IVF, Göteborg
- Project leader: K. Fischer (Chalmers, now Fraunhofer IWES)
- Funding: Swedish Energy Agency / Vindforsk III
- Focus on two different wind-turbine models (type 1: DFIG, type 2: IG with full power converter) at offshore and onshore sites, in total ~150 turbines, up to 4 years of data, LV converters

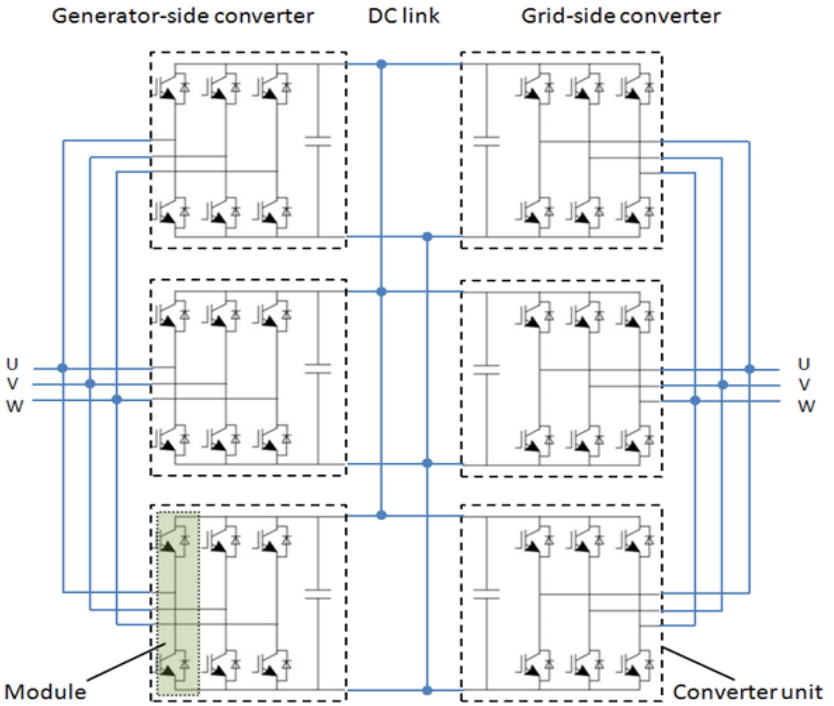
CONFAIL: Considered generator/converter topologies

IGBT-based converters in back-to-back configuration

DFIG with partially rated converter (ca. 30% of P_{WT}): 6 power modules (WT1)



IG with full power converter (100% of P_{WT}): 18 power modules (WT2)



[Sources: CONFAIL project (2012), Semikron]

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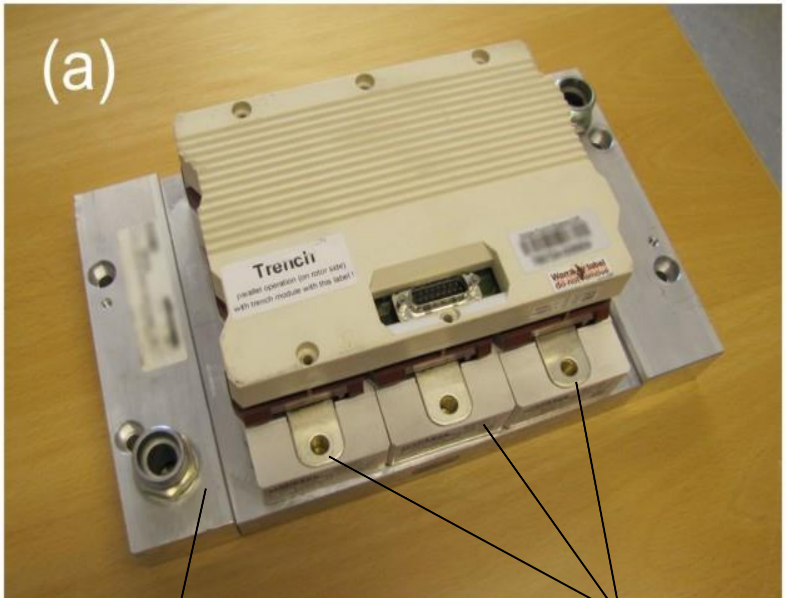
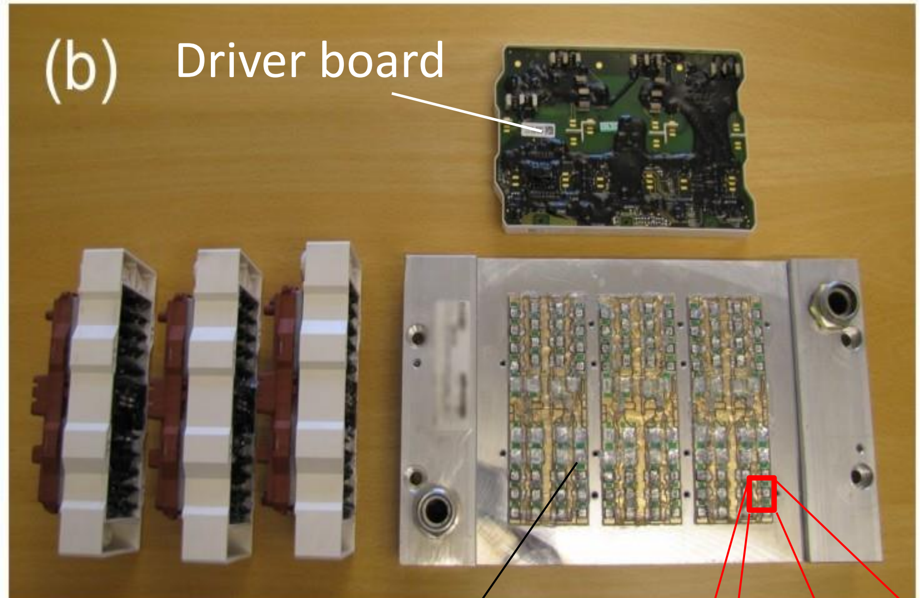
Converter module used in wind turbines

Exterior view



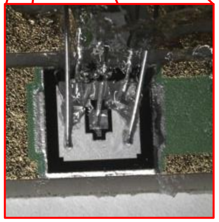
Disassembled module



AC terminals

Heat sink (water-cooled)

DCB with IGBTs and diodes, covered with potting compound

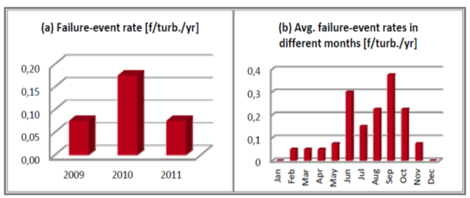


[Source: CONFAIL project (2012)]

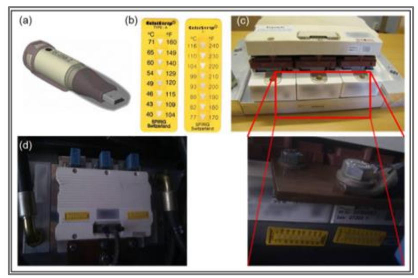
Root-cause analysis for power converters: Multi-track approach

Literature study, discussions at site

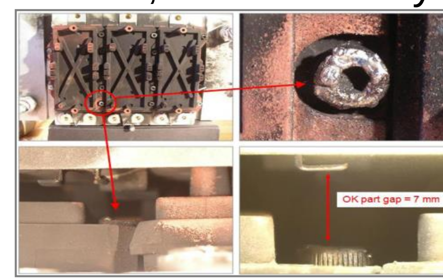
Failure-data analysis, correlation with environmental factors



Operating environment in the field



Measurements on failed modules, forensic analysis



Root-Cause Analysis workshops: Failure mechanisms and causes, countermeasures

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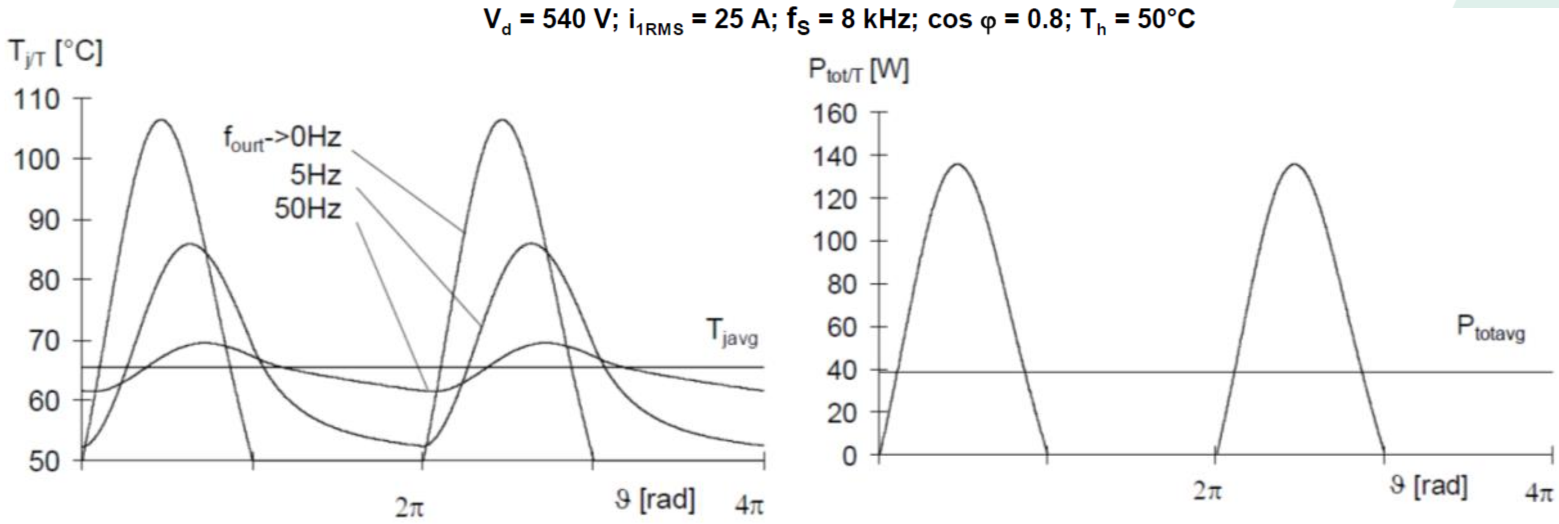
Literature: Focus on DFIG / thermomechanical failure

Generator-side converter in DFIG considered most critical, due to high currents at low frequencies
$\Longrightarrow$ severe load and thermal cycling $\Longrightarrow$ thermomechanical stress
$\Longrightarrow$ bond-wire and solder fatigue

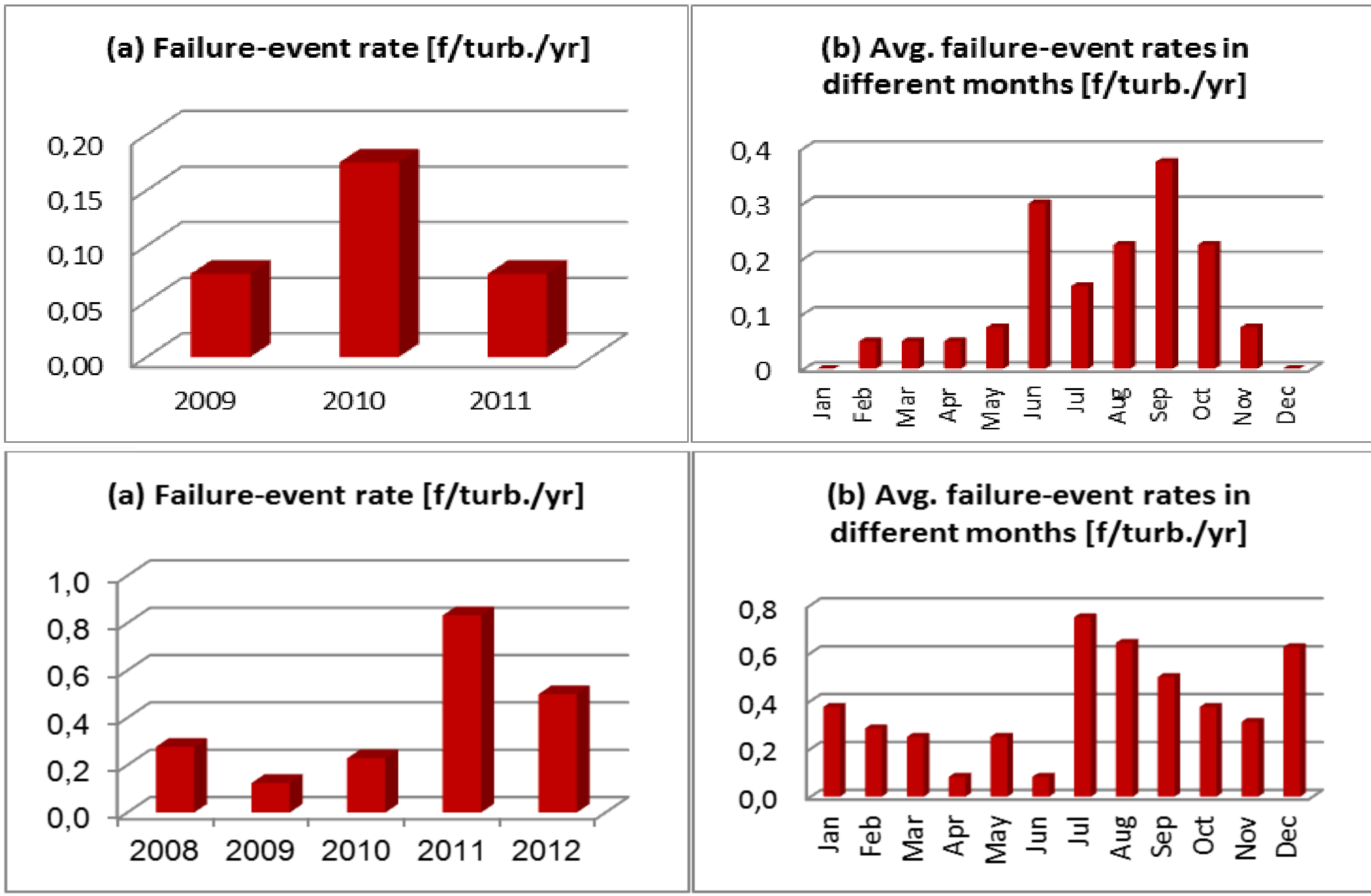


Figures: Simulated junction temperature and power dissipation characteristics of a 1200V/50A-IGBTin inverter operation for different fundamental output frequencies [Konrad (1997)]

CONFAIL: Power-converter failure rates, seasonal impact

WT type 1
(DFIG,
6 modules),
offshore

WT type 2
(IG with FPC,
18 power
modules),
offshore



[Source: CONFAIL project (2012)]

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CONFAIL: Effect of generator/converter topology and site

Average converter failure rates for the turbine models and sites of interest

	Wind park	Turbine model	Site	Avg. failure event rate [1/turbine/yr]	Avg. failure event rate [1/module/yr]
DFIG	Site A	WT1	Offshore	0.13	0.020
DFIG	Site B	WT1	Onshore	n.a.	n.a.
DFIG	Site C	WT1 WT1*	Onshore	0.15	0.025
IG with FPC	Site D	WT2	Offshore	0.39	0.021
IG with FPC	Site E	WT2	Onshore	n.a.	n.a.
IG with FPC	Site F	WT2	Onshore	n.a.	n.a.
IG with FPC	Site G	WT2	Onshore	n.a.	n.a.

[Source: CONFAIL project (2012)]

Similar failure rates per module in spite of different turbine topologies and sites

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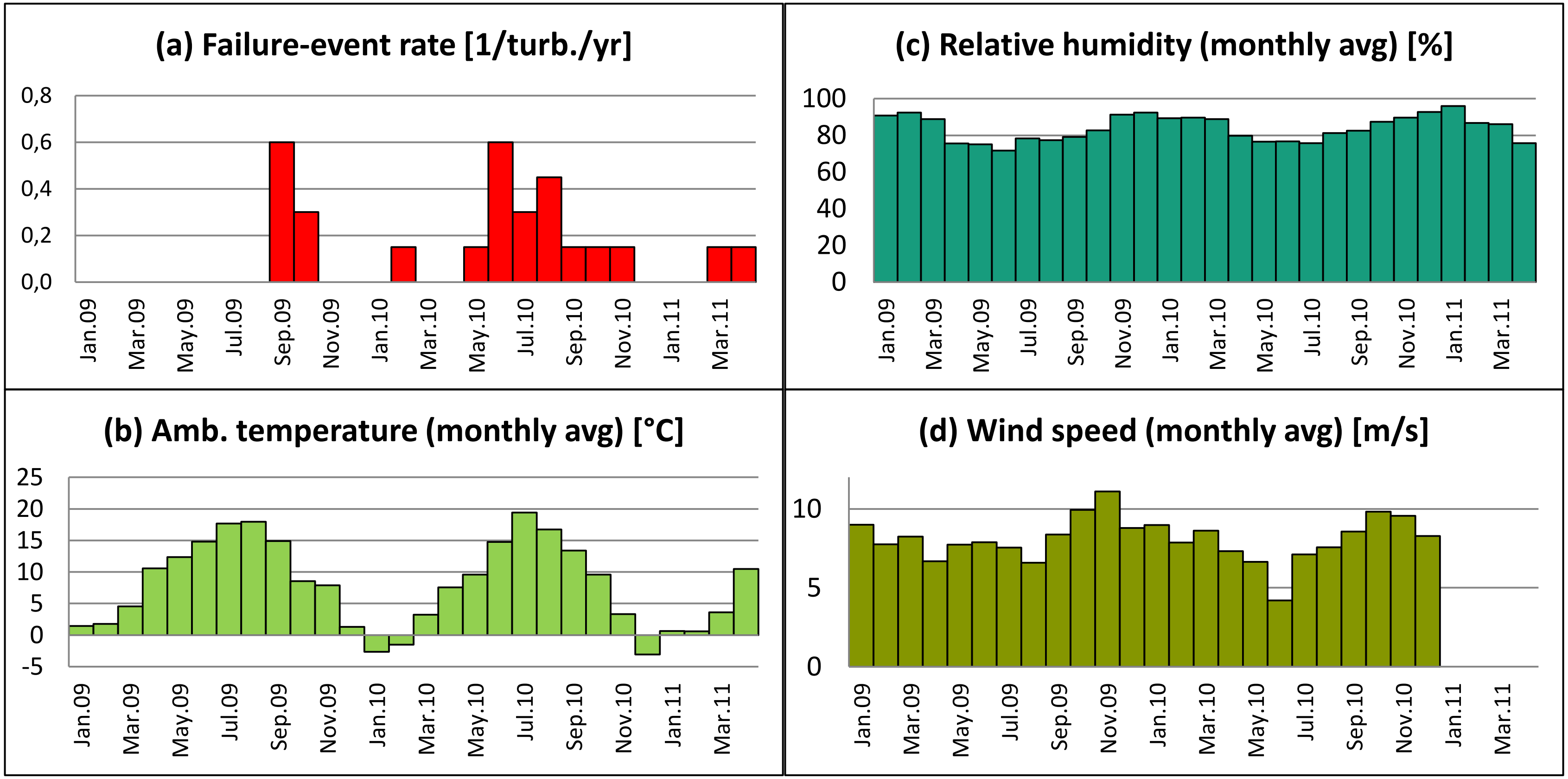
Correlation of converter failure with external factors

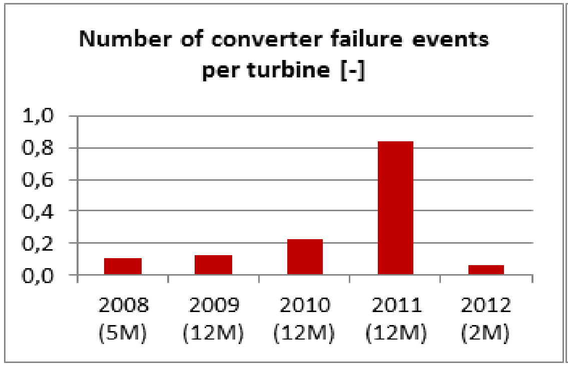
Correlation of monthly number of failures with average T, RH and v_{wind} ?

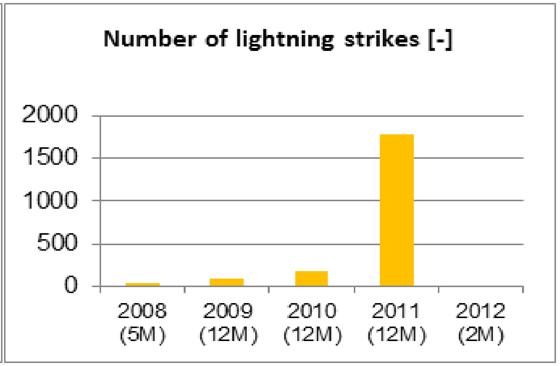


[Source: CONFAIL project (2012);
Climate data: Danish Metereological Institute]

Correlation of converter failure with external factors

Correlation of converter failure with lightning strikes?





Found correlations:	**WT type 1, offshore**	**WT type 2 (IG with FPC) offshore**	
	month-scale	month-scale	day-scale
Ambient temperature	+	o	o
Relative humidity	-	+	o
Wind speed	o	+	++ (but no corr. with explosion failure)
Lightning strikes	?	++	++ (esp. strong with explosion failure)

[Source: CONFAIL project (2012)]

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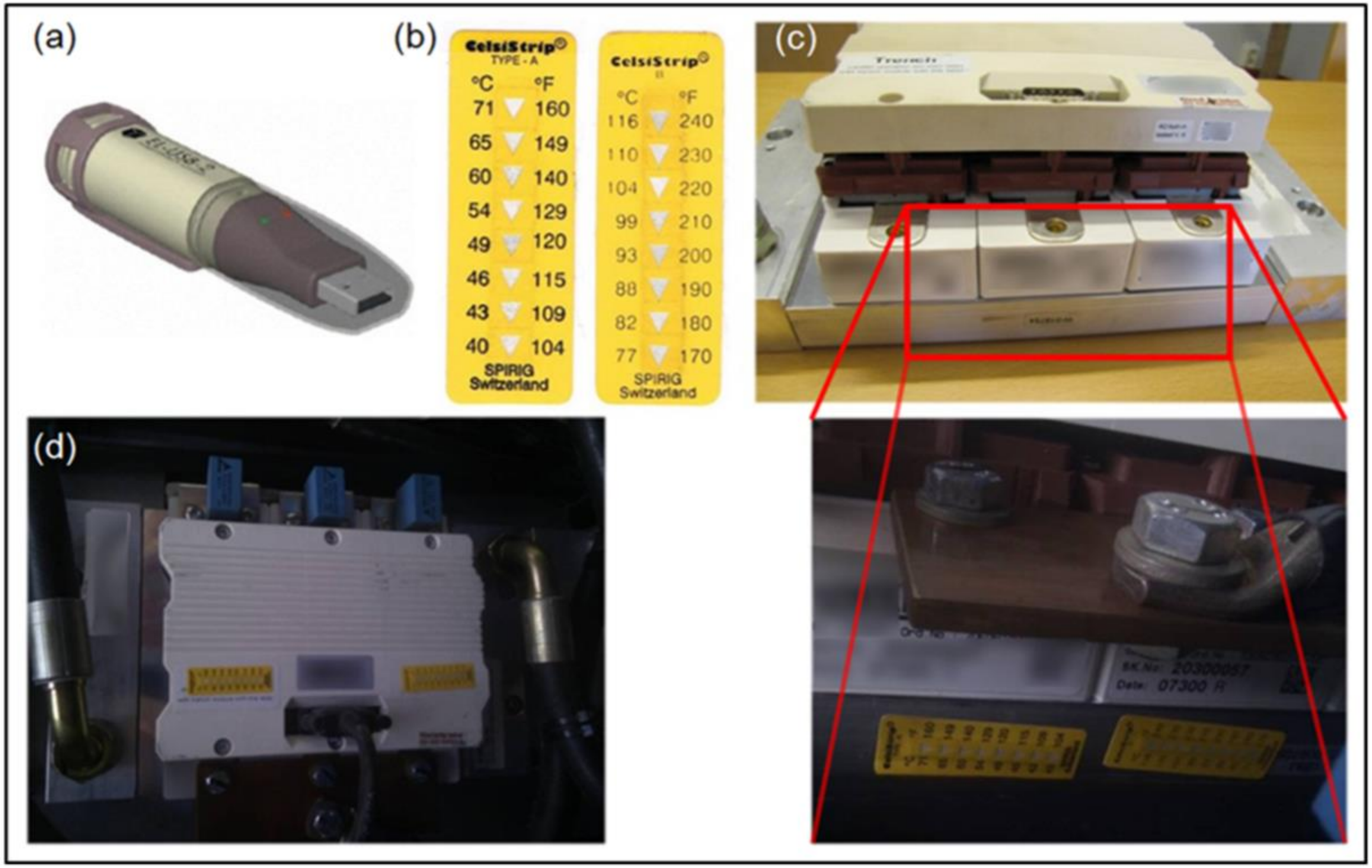
Field measurements inside converter cabinets



[Source: CONFAIL project (2012)]

(a) Temperature and humidity loggers, (b) thermo-sensitive tape, (c,d) tape positions on modules

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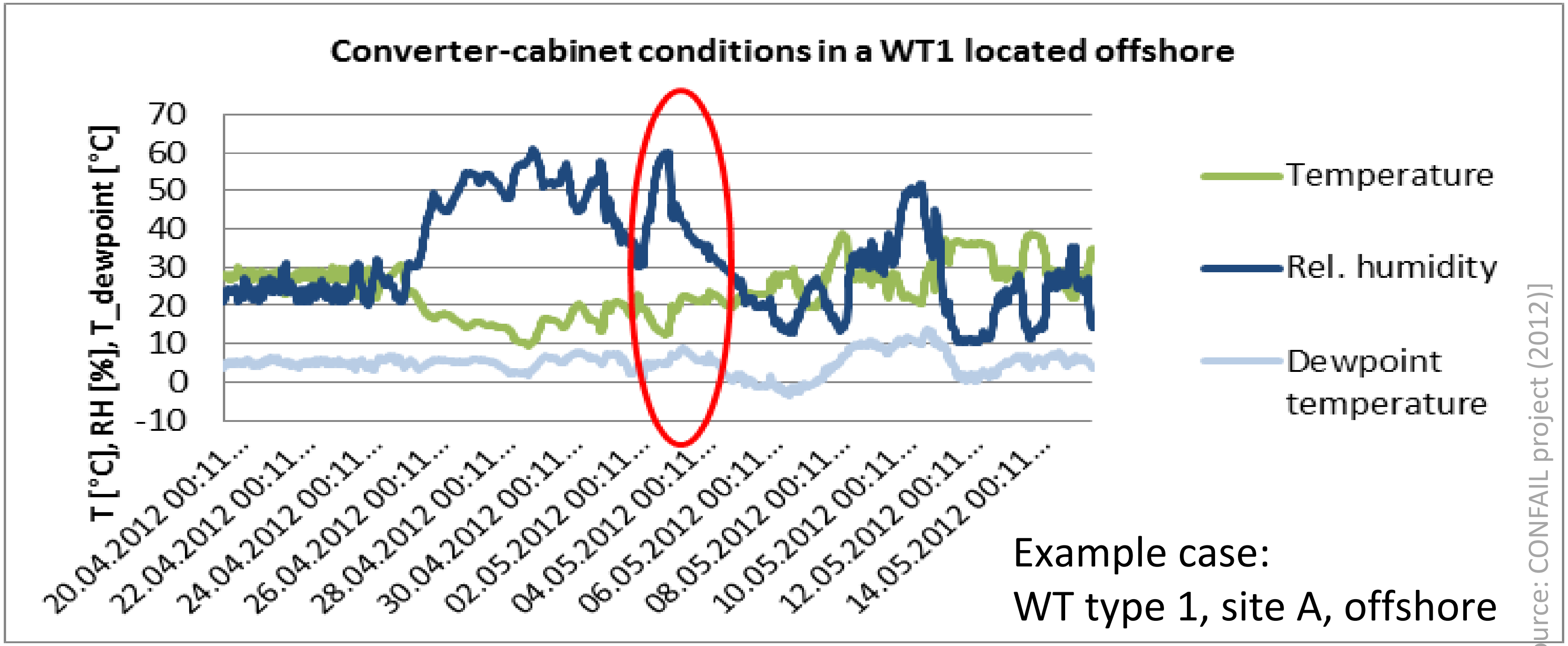
Operating environment inside converter cabinets



[Source: CONFAIL project (2012)]

Main findings:

- No problematic temperature levels found
- Risk of condensation failure during start-up after long standstill confirmed

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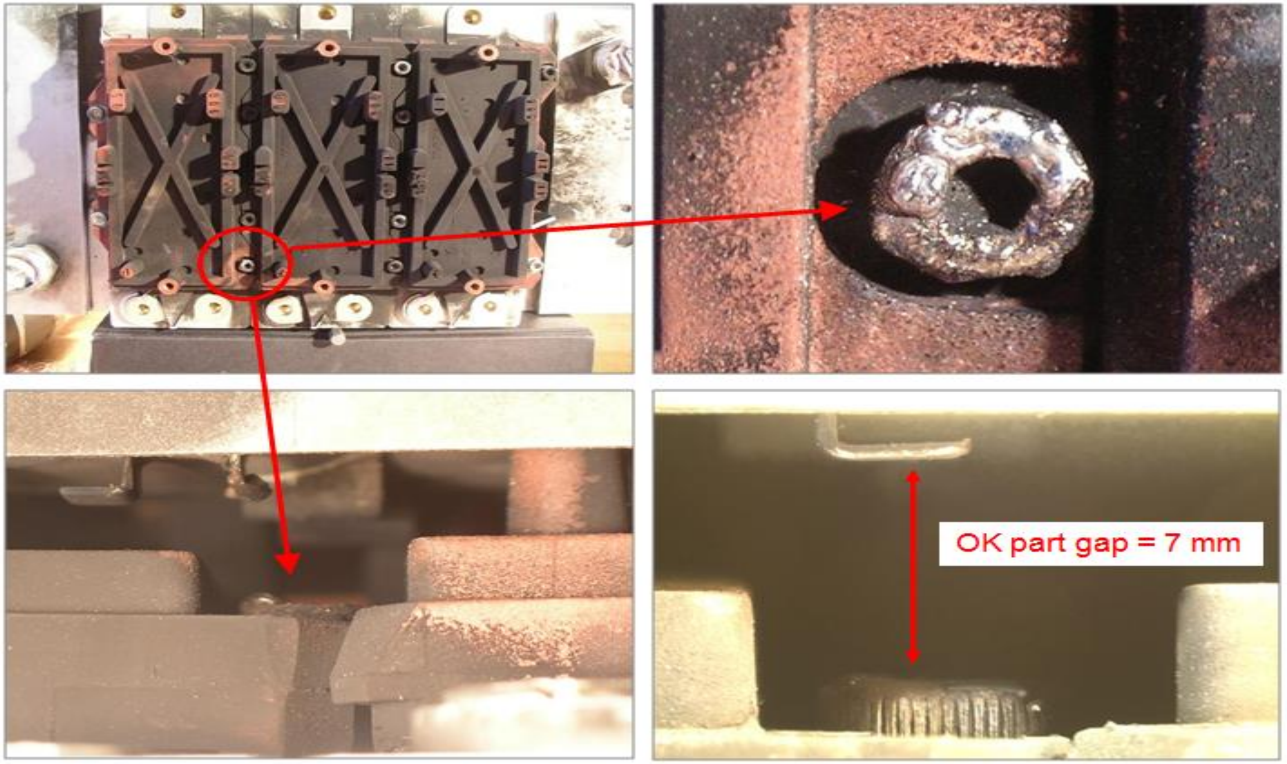
Forensic analysis of damaged power modules

Evidence of high-voltage sparkover between PCB cooling fin and a screw (heat sink)



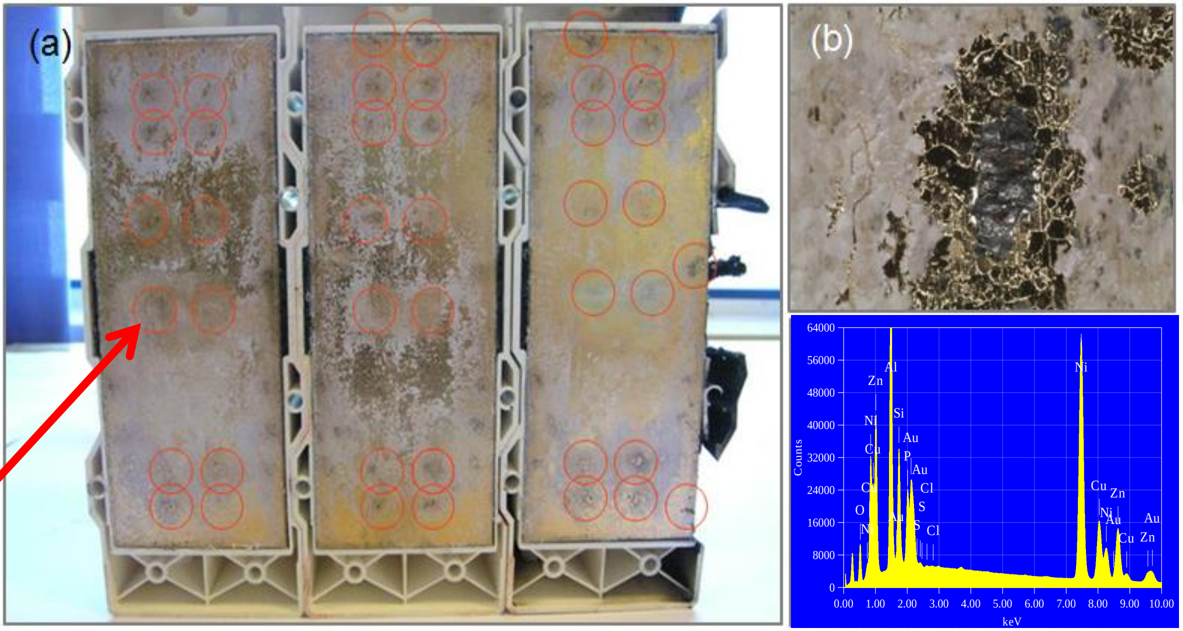
[Source: CONFAIL project (2012)]

Possible explanations e.g. electrical overstress due to lightning event, air gap reduction by foreign object

Forensic analysis

Degraded thermal grease between DCB and heat sink

Possible causes: ageing, dry-out, pumping effects, …



[Source: CONFAIL project (2012)]

Spots on DCB and aluminium heat sink:
Mechanisms of "fretting corrosion" (due to thermo-mechanically induced relative movements in combination with mechanical pressure)

⟹ Overheating due to increased thermal resistance to heat sink?

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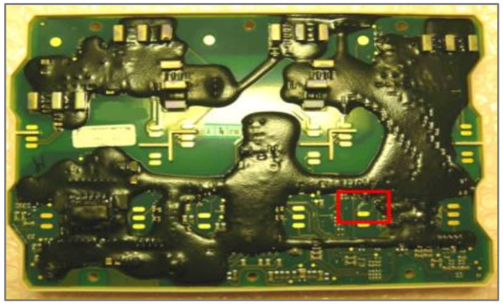
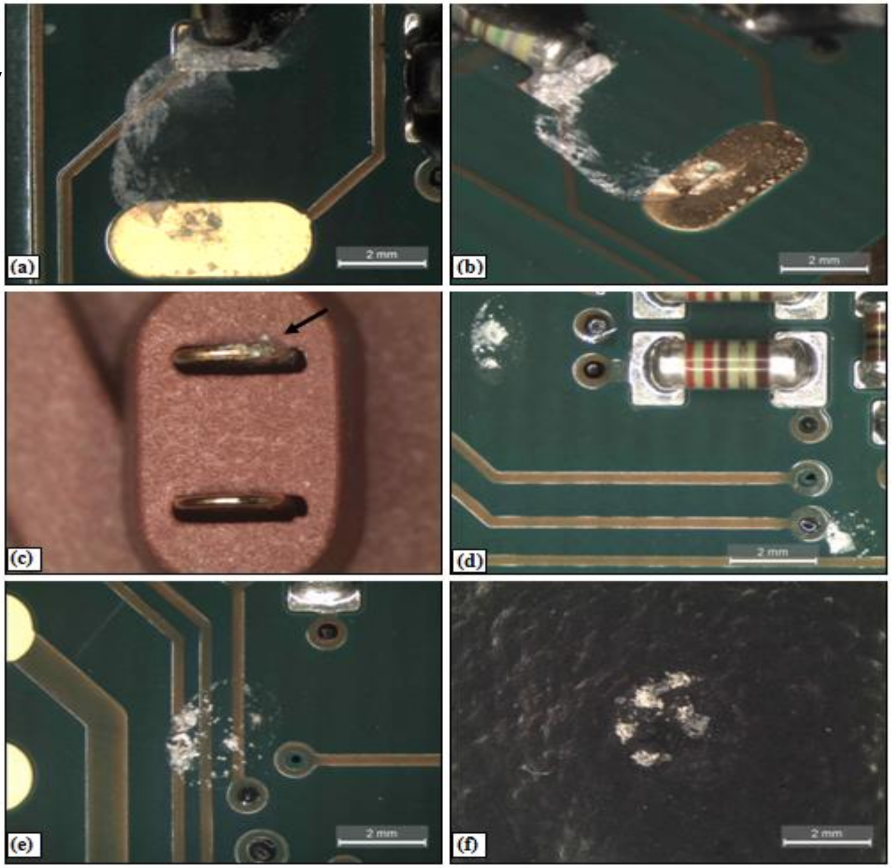
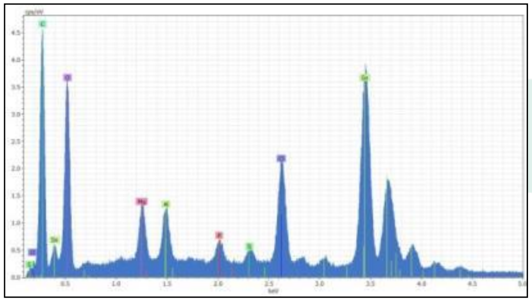
Analysis of converter driver-boards



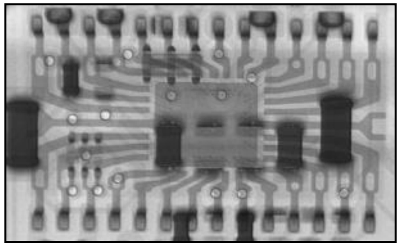
Optical microscopy



SEM and EDS



X-ray miscroscopy



[Source: CONFAIL project (2012)]

Contamination with salt and corrosion products found on one driver-board

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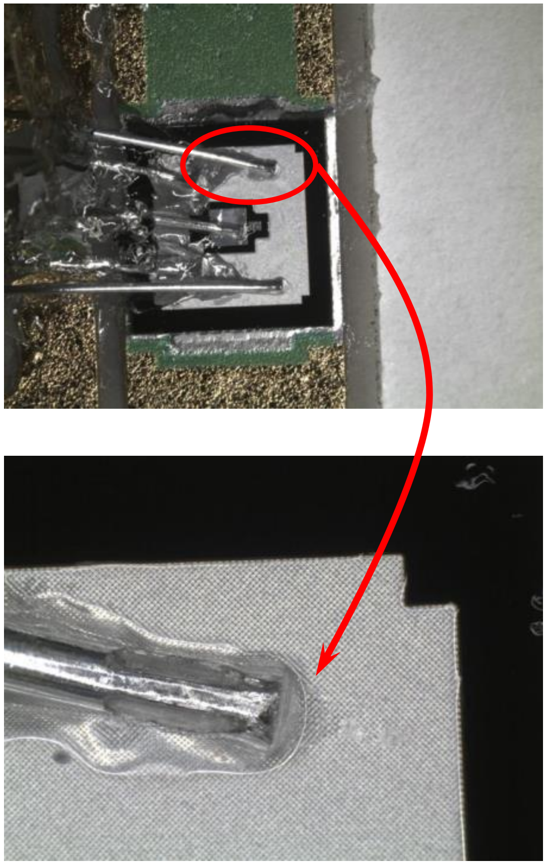
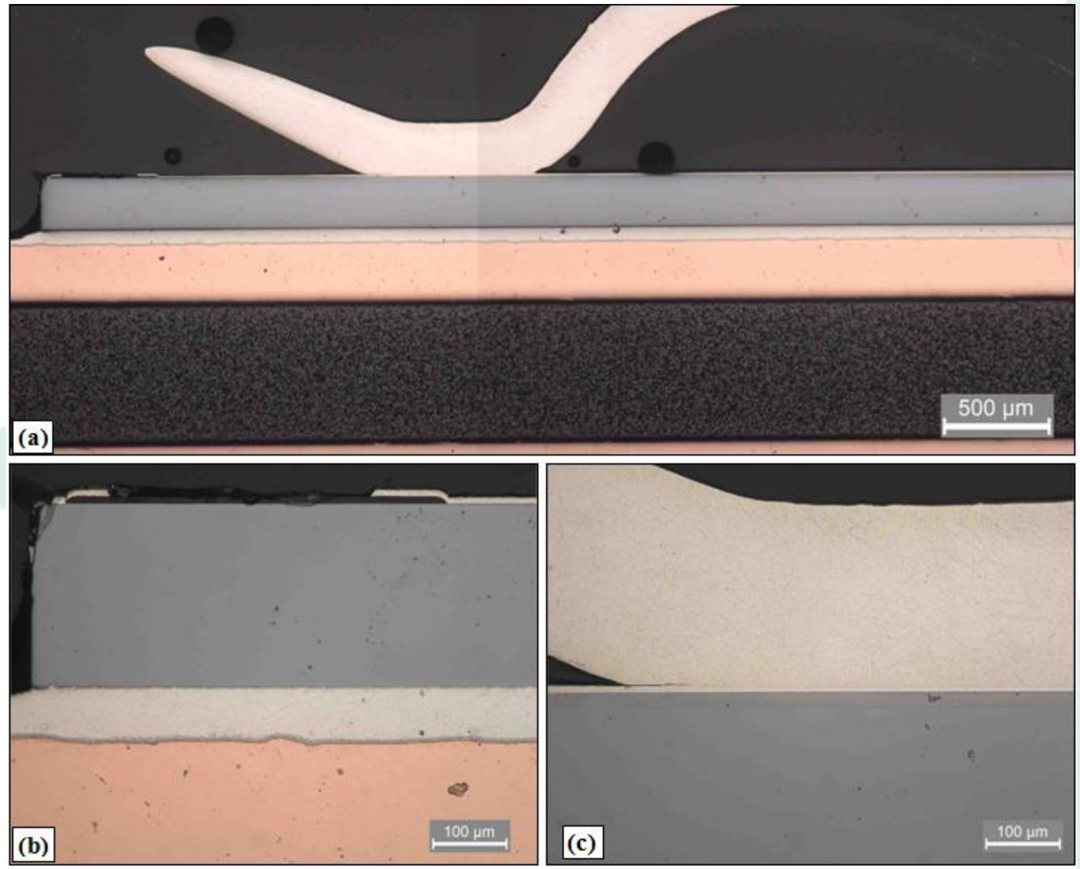
Microscopy inspection of the bond wires and die attach





[Source: CONFAIL project (2012)]

No indications of the “classical” converter reliability issues, (bond-wire or solder damage) found

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Outlook

- CONFAIL pre-study:
  - Classical converter reliability issues (solder degradation, bond-wire damage) seem to play a minor role in wind turbines at present
  - Indications for insufficient protection (salt, condensation, foreign objects)
  - Indications for electrical overstress (correlation with lightning events)

- Next step: from indications towards clear evidence & solutions
  - Clarify converter-failure causes and mechanisms based on extended failure-data analysis, directed field measurements and hardware analysis

  ⟹ extend the scope to further wind-turbine models, additional topologies, MV technology, sites with different climatic conditions, …

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Outlook: R&D cluster on reliable power electronics for wind turbines (in preparation)

Project focus and objectives:

- Improving reliability and availability of frequency converters in wind turbines
- Root-cause analysis, solutions for existing and new turbines
- System behaviour in dynamic operation
- Condition monitoring for electronics
- Fault-tolerant generator/converter concepts

Project partners:

- Fraunhofer IWES, Fraunhofer ISIT
- 4 universities
- 22 industry partners

Duration: 2013 – 2016 **Budget:** 8 M€

Research partners:

Fraunhofer IWES

Leibniz Universität Hannover

Institut für Antriebssysteme und Leistungselektronik

ForWind Zentrum für Windenergieforschung

Fraunhofer ISIT

CAU Christian-Albrechts-Universität zu Kiel

FHW Fachhochschule Westküste Hochschule für Wirtschaft & Technik

Fachhochschule Kiel University of Applied Sciences

Industry partners:

REpower Systems, juwi, SSB Wind Systems, Woodward, Dispatch Energy, Danfoss, Leine Linde Systems, Vishay, Suzlon, FeCon, PNE Wind, Reese +Thies, wpd, itec, EWE, ZOPF, Availon, Bender, Semikron innovation + service, Vattenfall, Gothaer, Basler Versicherungen

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THANK YOU FOR YOUR ATTENTION

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