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Integrated Motor Drive Inverter with Active Fault Handling for Aerospace Applications

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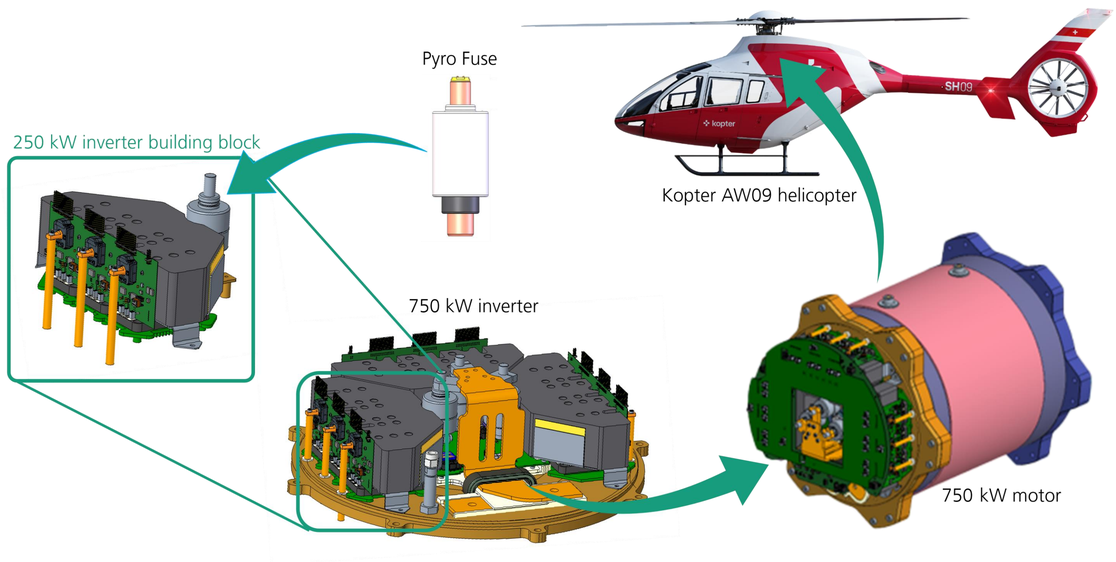
BayLu25 Project HeDrive
Helicopter electric Drive train

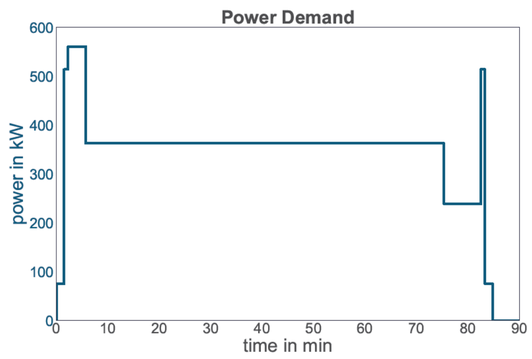
- The HeDrive Project is a technology demonstrator aimed at a multiphase motor and a multiphase drive inverter with new fault handling capabilities, for the Kopter's AW09 light-weight helicopter propulsion system (~750 kW) powered by hydrogen fuel cells.
- Within the framework of the Bavarian Aviation Research Program BayLu25, the project focused on the integration of a DC link capacitor-integrated pyrotechnic emergency disconnection element for faulty system components.
- This project is an implementation of a safe and fault-tolerant drive that enables error handling at the inverter level with upstream emergency shutdown devices.
- The resulting system combined the functional redundancy of twin-engine helicopters with the efficiency, maintainability, and emission advantages of electric propulsion.



Mission Profiles

- 13 mission profiles analyzed
- Mission profiles from AW09 typical applications
- Peak power requirements of up to 700 kW
- 80 % are expected to remain feasible through electrification

EMS Field Mission Profile



Inverter Parameters

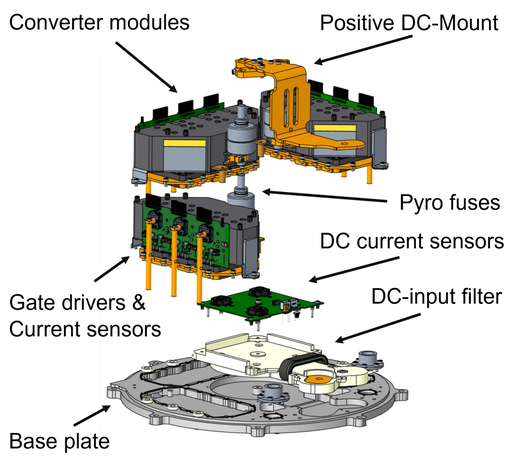
- Nominal inverter power: **750 kW**
- DC voltage range: **700 V…850 V**
- Switching frequency: **30 kHz**
- Peak efficiency: **98.5 %**
- Power density: **20 kW/kg**

Key Features

- 3x3 phase electric motor winding systems with a separated structure
- 3 independent 250 kW inverter building blocks combined to one 750 kW inverter
- Latest generation of SiC power modules CAB760M12HM3 from Wolfspeed
- Standalone modular fault detection on the 250 kW inverter block level
- Redundant fault detection based on multiple fault indicators
- Active protection mechanisms based on pyrotechnic fuse elements

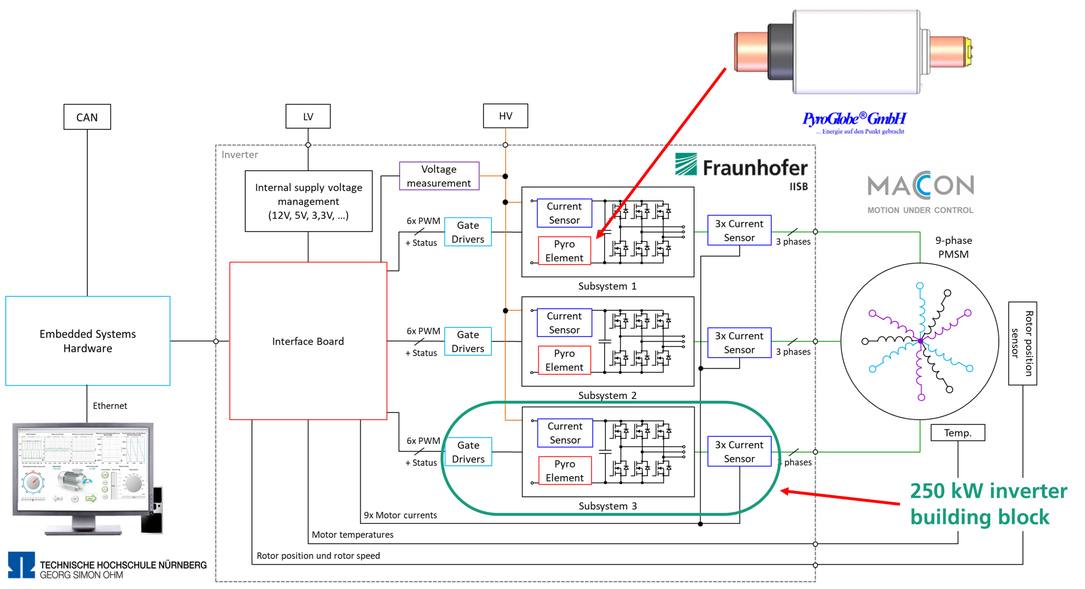
Inverter Design Layout

- Common-mode input filter
- Pyro fuse with integrated DC sensor
- Customized DC link capacitors
- Power modules between the DC link capacitors and cooling plate
- Copper cooling plate for reduced thermal resistance
- Cooling channels integrated into the base plate
- Gate drivers with integrated AC sensor



System Architecture

- High-power-density integrated inverter design (24 kW/kg)
- Two-level inverter topology for maximized efficiency (peak of 98.5%)
- With a 9-phase system, the parallel connection of the discrete packaged transistors is avoided
- Modular inverter architecture based on independent 250 kW building blocks
- Circular arrangement enabling direct motor integration and compact packaging
- A custom-designed cooling circuit integrated into the mounting plate between the motor, the inverter, and the motor cooling circuit
- Distributed current sensing on DC and AC side for subsystem monitoring
- Pyro fuse-based subsystem isolation for modular fault containment
- Interface board for centralized control and supply voltage management
- Fail-operational operation with continued functionality under subsystem faults
- Custom DC-link capacitor design for minimized voltage ripple [1]
- DC-link capacitance dimensioned for stable single-subsystem operation
- Overdrive capability of remaining subsystems during fault scenarios



1 Hilpert, C. Bentheimer, T. Mueller, B. Eckardt, Investigation of novel multi-phase field-Oriented drive inverter control with fail-operational capabilities for aircraft applications, in: PCIM Europe Digital Days 2021; International Exhibition and Conference for Power Electronics, Intelligent Motion, Renewable Energy and Energy Management, 2021, pp. 1–7.

2 L. Kuhn, M. Meindl, C. Bentheimer, and M. März, "Hardware-based electric drive train fault detection unit enabling fail-operational capabilities for aviation applications," Aero-space Science and Technology, vol. 172, p. 111681, 2026, doi: 10.1016/j.ast.2026.111681.

Project
The Bavarian Aviation Research Program BayLu25 supported the research under the project number "BLU-2109-0014 HeDrive - vollel-ektrischer Antriebsstrang für Hubschrauber".

Funded by:
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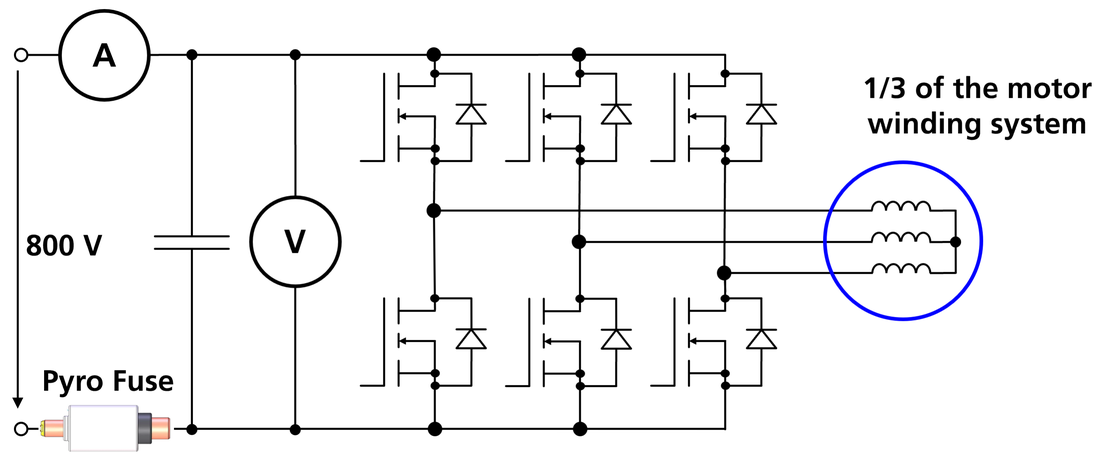
Failure Handling



Failure Cases: Short circuit

- Bridge / DC link short circuit
- Top switch short circuit
- Bottom switch short circuit
- 2-phase (motor) short circuit
- 3-phase (motor) short circuit

System Response:

- Pyro fuse is triggered
- Open all switches for the affected 3-phase system
- Pulsed AKS to mitigate charging DC link capacitor

- Loss of 1/3 of propulsion power
- Preservation of 2/3 propulsion power

Failure Cases: Open circuit

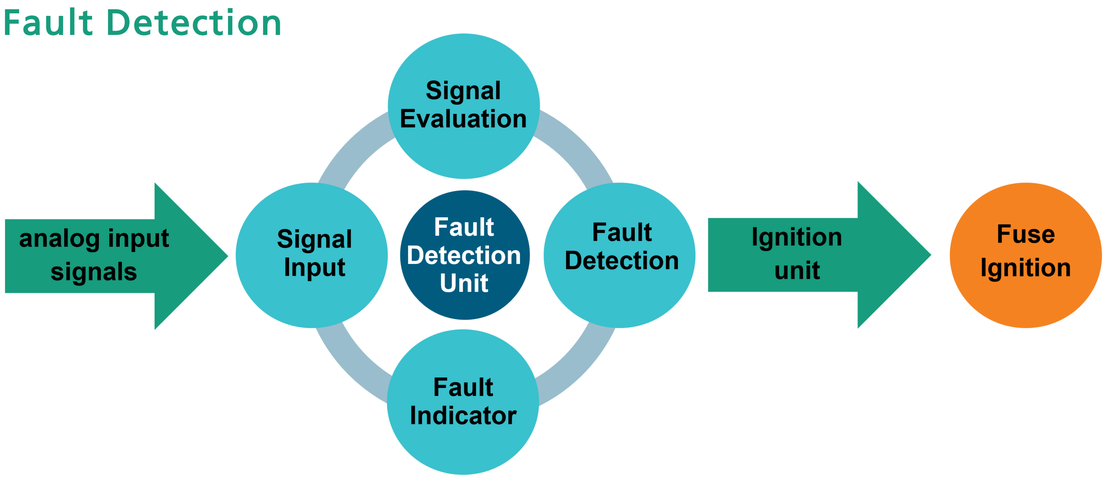
- Top switch open circuit
- Bottom switch open circuit
- 1-phase (motor) open circuit
- 2-phase (motor) open circuit
- 3-phase (motor) open circuit

System Response:

- Pyro Fuse is not triggered
- Open all switches for the affected 3-phase system
- Pulsed AKS to mitigate charging DC link capacitor

- Loss of 1/3 of propulsion power
- Preservation of 2/3 propulsion power

Fault Detection



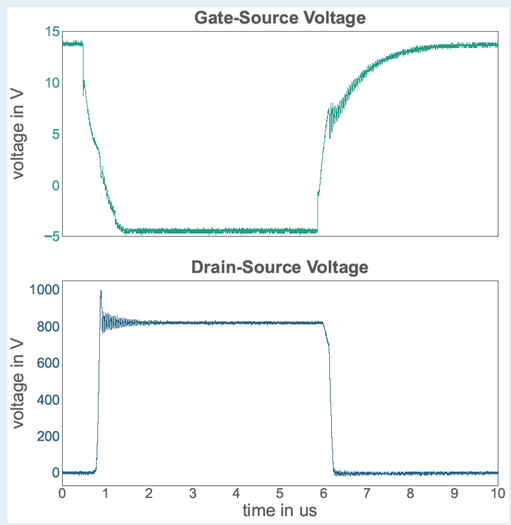
- Standalone modular fault detection on the 250 kW inverter block level
- Redundant fault detection based on multiple fault indicators
- Unique hardware-based fault detection system for complex multiphase drive train topologies [2]
- Fault current direction taken into account
- Fault detection delay is independent of fault current energy
- Reliable fault isolation at low short circuit currents
- Fault clearing and isolation in less than 3 ms

Hardware Demonstrator and Testing Results

- Three 250 kW inverter building blocks built up and tested
- The complete 750 kW inverter system assembled and tested on the in-house Megawatt motor drive test bench

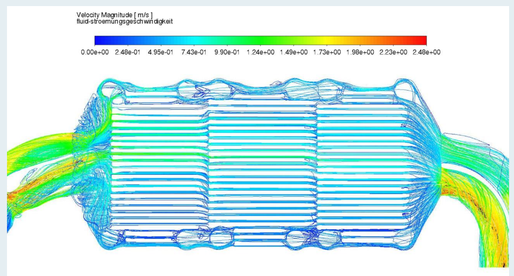
Switching Performance

- Nominal current level of $300\ \mathrm{A_{RMS}}$
- Tested current level of $514\ \mathrm{A}_{peak}$
- Turn on $\mathrm{dU/dt}$ of about $10\ \mathrm{kV/\mu s}$
- Turn off $\mathrm{dU/dt}$ of about $5\ \mathrm{kV/\mu s}$

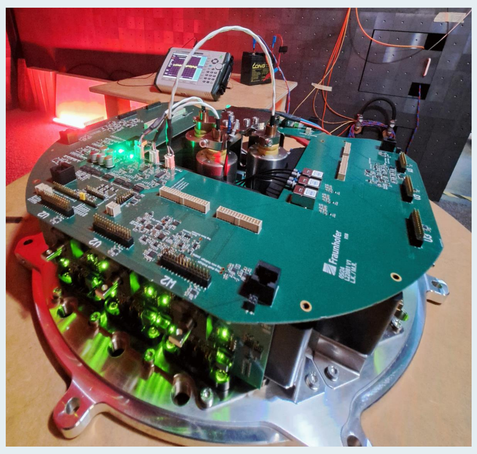


Steady State Thermal Simulations

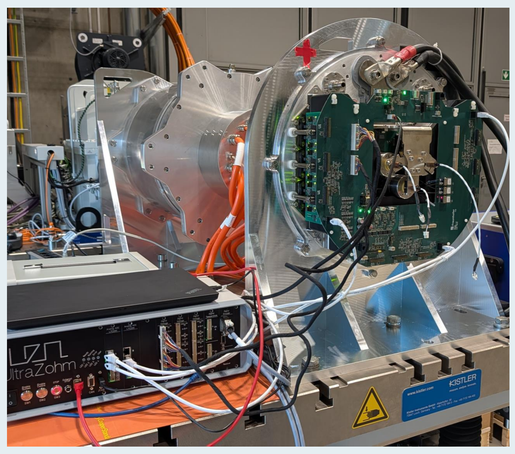
- Optimized by using CFD software to improve flow and thermal performance
- Nominal flow rate of 20 l/min
- At inlet temperature of 60 °C and a worst-case power loss of 7.5 kW, the maximum chip temperature is approximately 100 °C
- Safety margin enables system overdrive during fault scenarios.



Assembled 750 kW Inverter



Hardware Demonstrator Testbench



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