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Fraunhofer IISB

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Ultracompact Symmetrical Medium Voltage DC-DC Converter for Electrified Aircraft

Malavika Santhosh Kumar, Moritz Kerscher, Marc-Pascal Boßle, Philipp Hörauf

Objectives

- Compact converter with high power density.
- Lightweight, aviation-ready concept.
- Symmetric bi-directional converter for an output voltage of 1600 V.
- Cascaded control loop for output voltage and current control.

Symmetrical DC-DC Converter

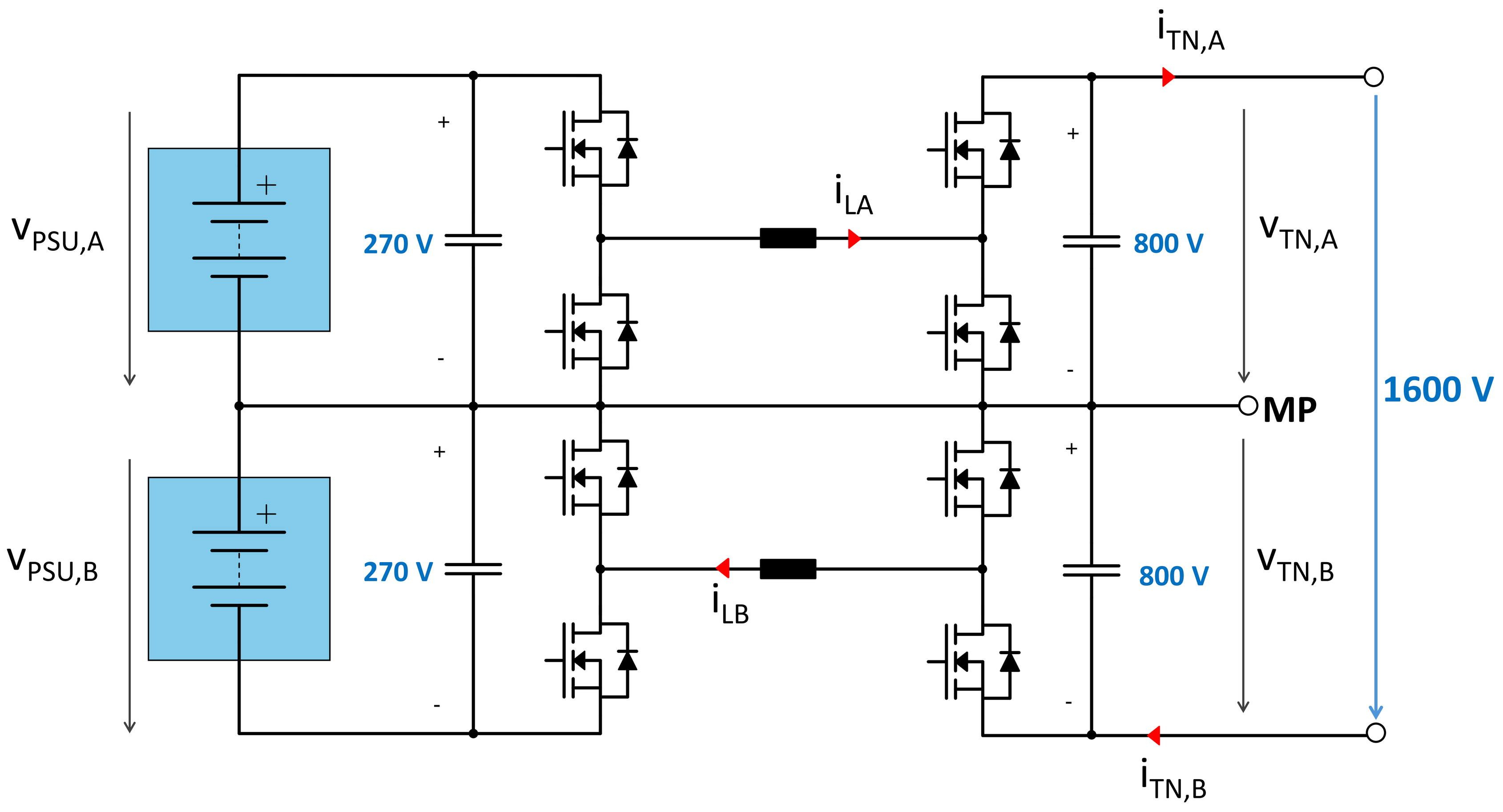

Fig. 1 *Circuit diagram of the symmetric DC-DC converter in boost mode*

- Multilevel topology buck-boost converter with sides A and B stacked over each other.
- Common current path MP for both sides A and B.
- 1600 V is achieved with less clearance and creepage distance.

Voltage [V]	Altitude [km]	Minimum clearance distance [mm]	Minimum creepage distance [mm]
1000	0	0.8	5
	10	2.42	

Table. 1 *Minimum clearance and creepage distances [1]*

Cascaded Control Structure

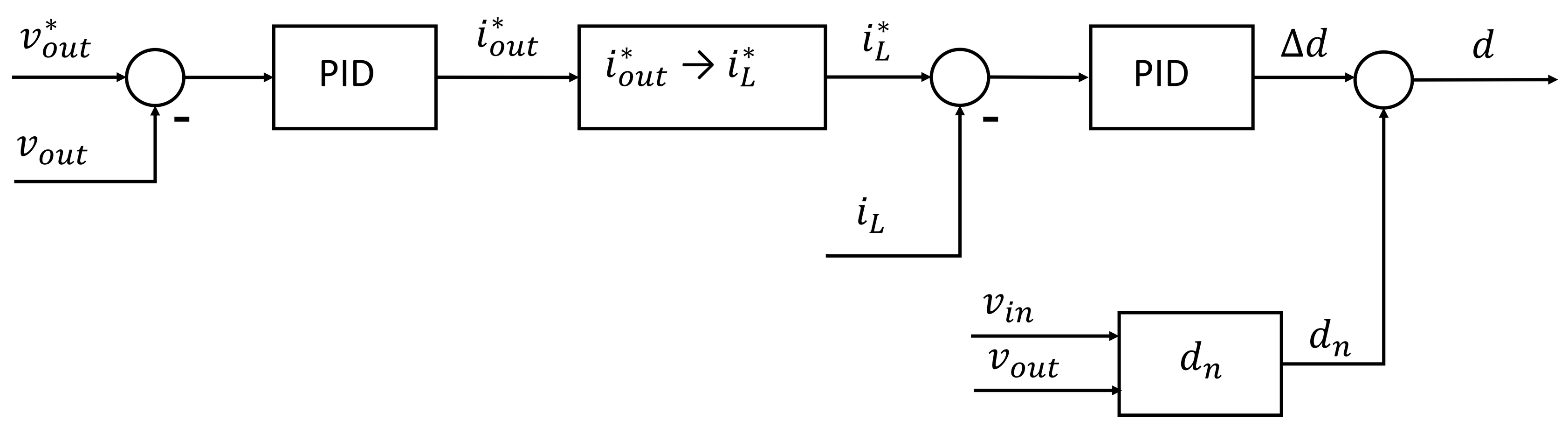

Fig. 2 *Block diagram of the full control loop*

- PWM modulation with duty cycle between -1 and 1 for buck or boost mode.
- When d>0, operation in boost mode.
- Inner phase current control loop.
- Outer control loop sets reference for TN current.
- PID regulator is used in both loops.

Cube Shaped Mechanical Structure

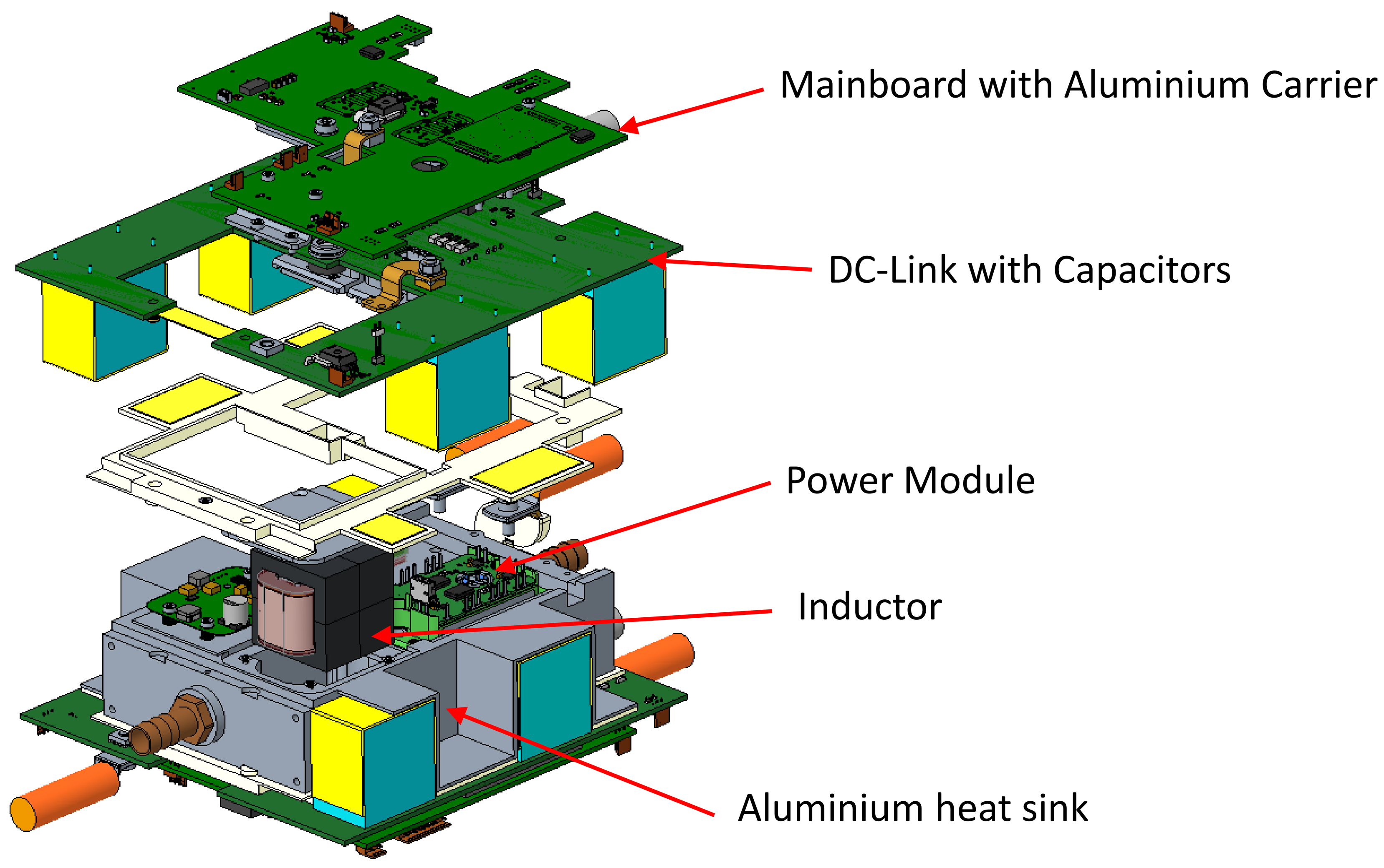

Fig. 3 *Mechanical structure of the converter*

- Cubical structure with weight optimized 3-D aluminium heat sink.
- DC-Link capacitors and PCBs designed for symmetric geometry.
- Controller board (Mainboard) is stacked over the DC-Link PCB.
- Inductors placed directly inside heat sink structure.
- Compact design: one cooling channel cools all components.

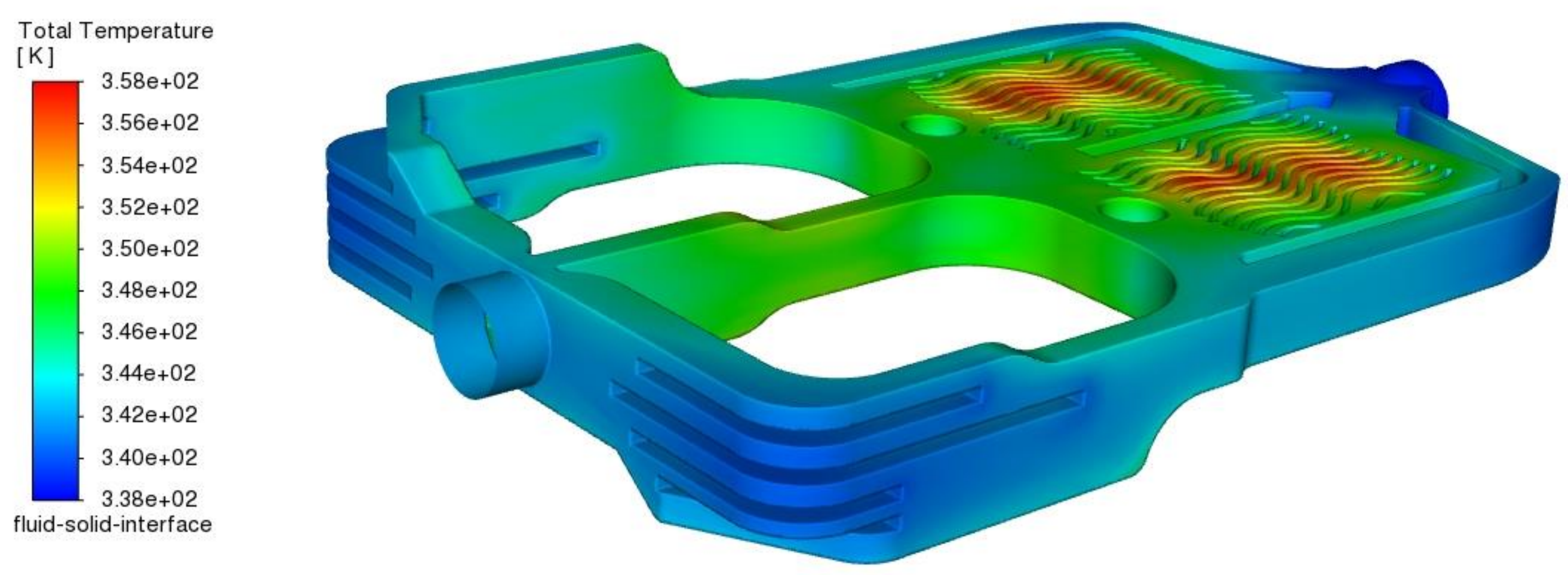

Fig. 4 *Fluid volume simulation of the cooling system*

References

[1] *Insulation coordination for equipment within low-voltage supply systems- Part 1: Principles, requirements and tests*, IEC 60664-1, International Electrotechnical Commission, 2020

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Experimental Setup

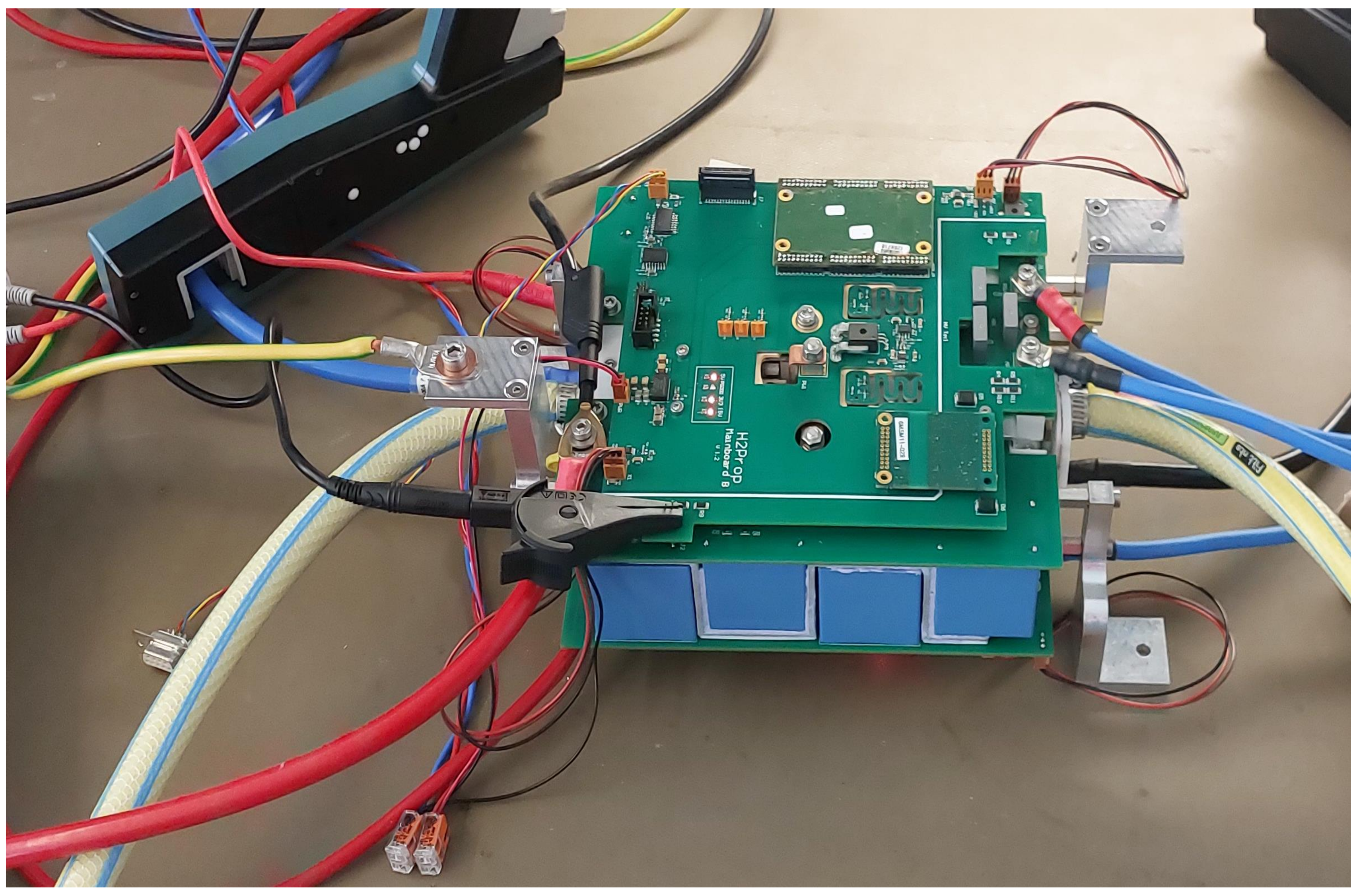

Fig. 5 Experimental prototype of the converter

- Dimensions are 21 x 20 x 9 cm.
- SiC MOSFET Modules used for each half-bridge.
- Total weight without metal stands is 4.4 kg.
- Water cooling with a temperature of 7 °C and flowrate of 7 l/min.
- High voltage differential probes and current probes were used for measurements.

Efficiency

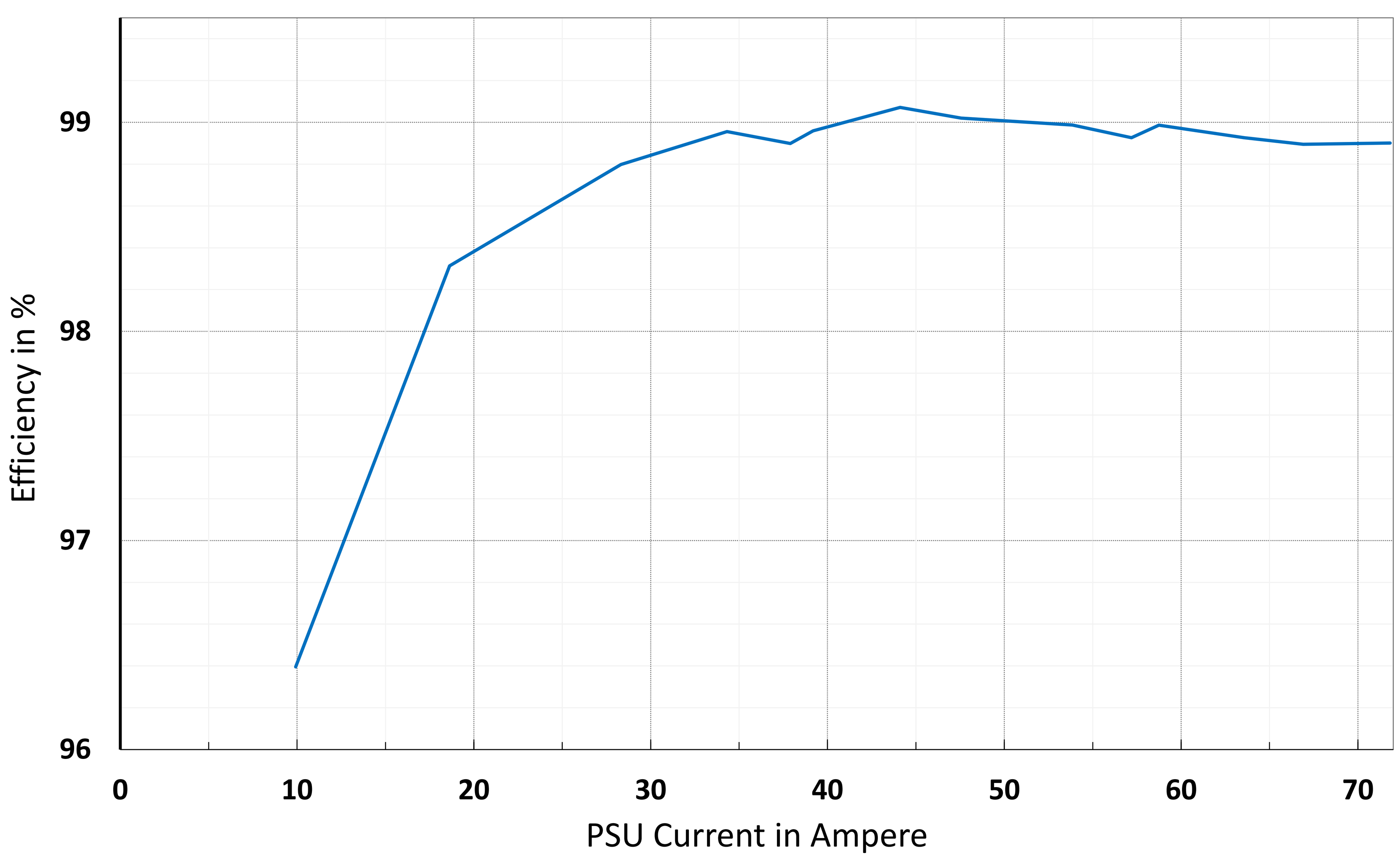

Fig. 6 Efficiency curve of converter side A

- Only side A is operated for efficiency calculations.
- Due to symmetric structure, efficiencies of both sides A and B are the same.
- PSU (Input) voltage is 270 V.
- TN (Output) voltage is 600 V.
- PSU current is varied in steps of 5 A up to 75 A.

Phase Current Controller Verification

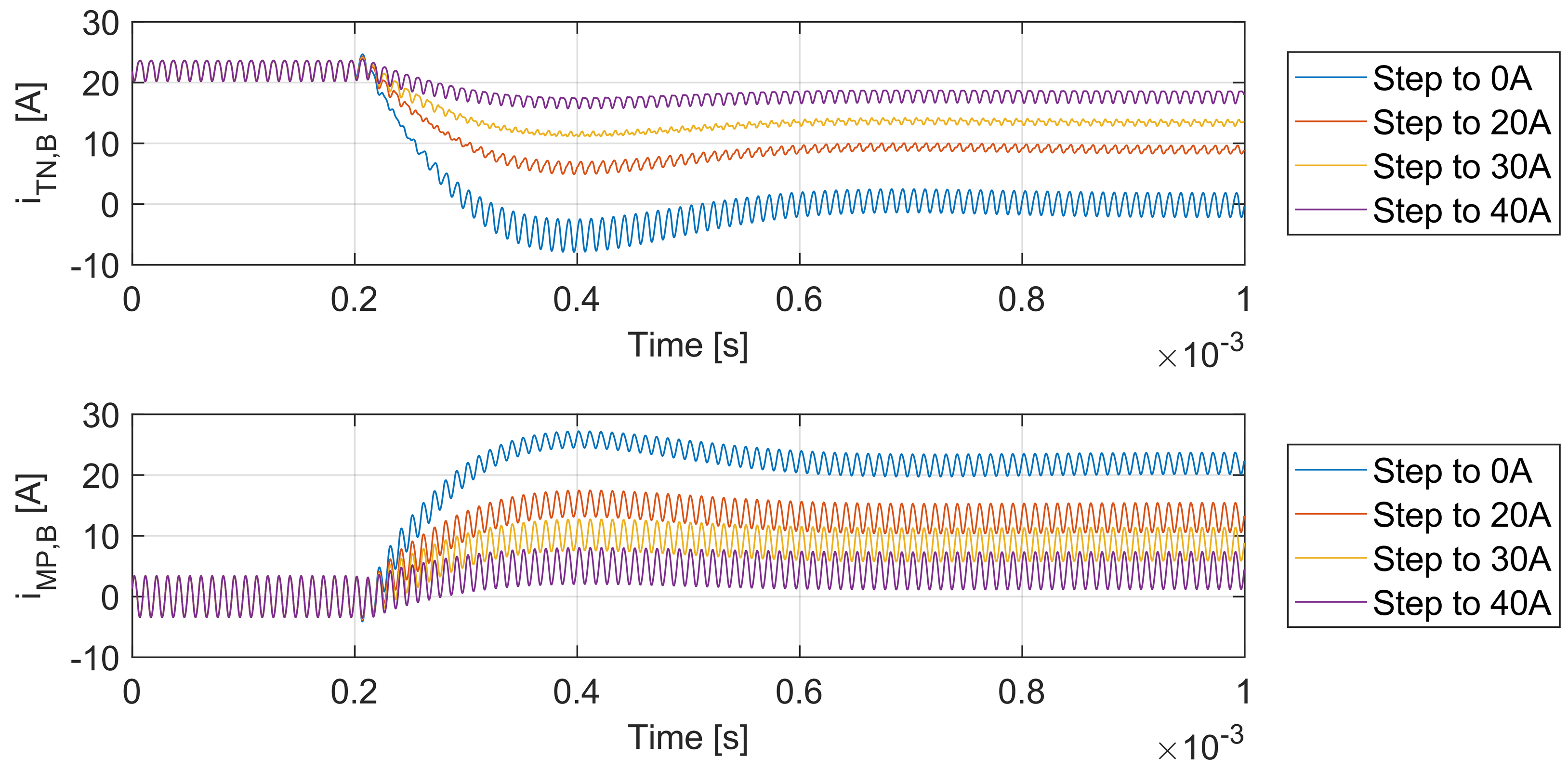

Fig. 7 Simulation of asymmetric output current with phase controller active

- PSU voltage is set to ± 270 V , TN voltage is set to ± 600 V, and PSU current is 50 A.
- A change in the reference phase current of side B is issued at 0.2 ms.
- Reference steps between -10 A and -50 A.

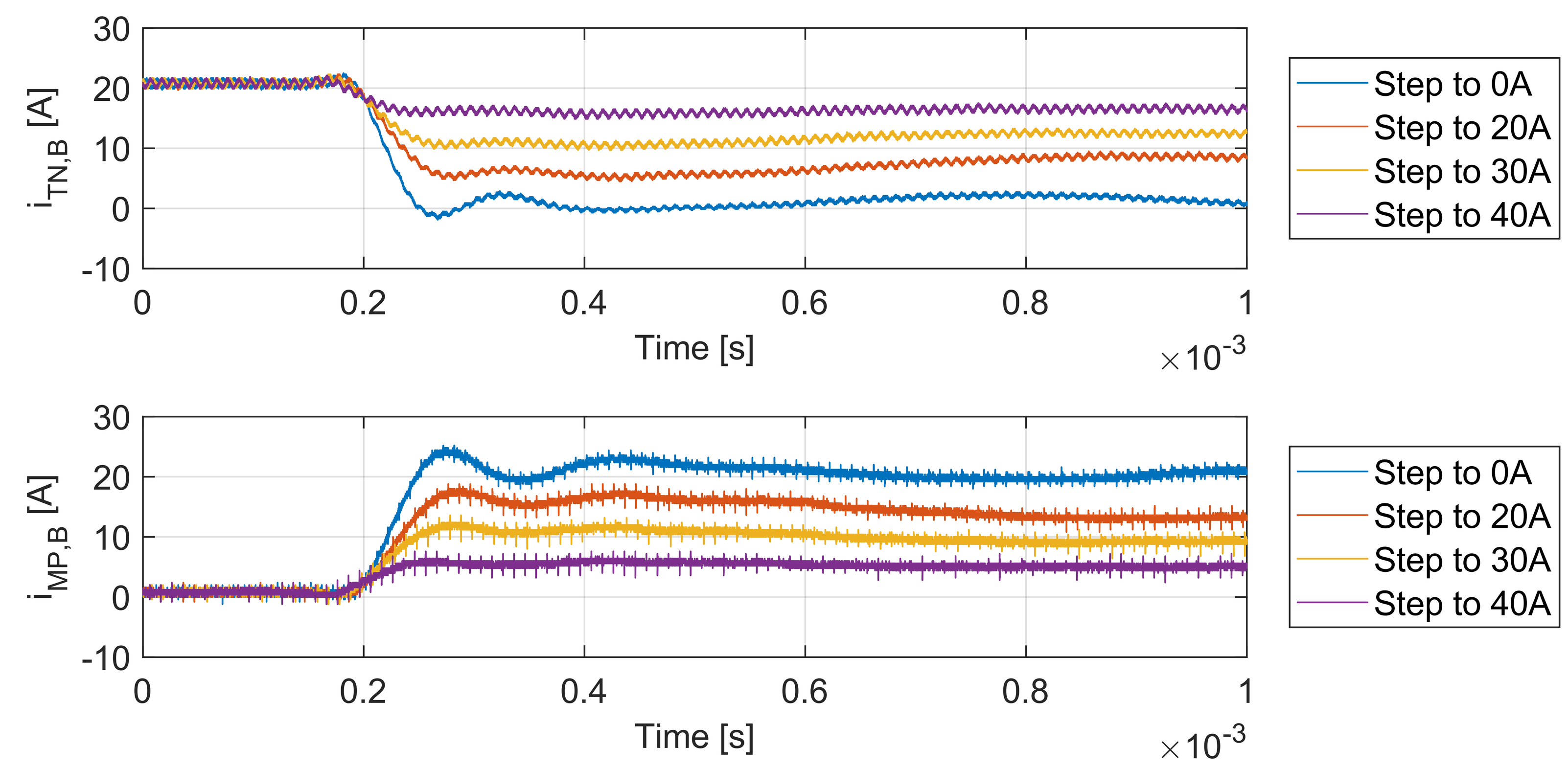

Fig. 8 Experimental results of asymmetric load test

Full-power test

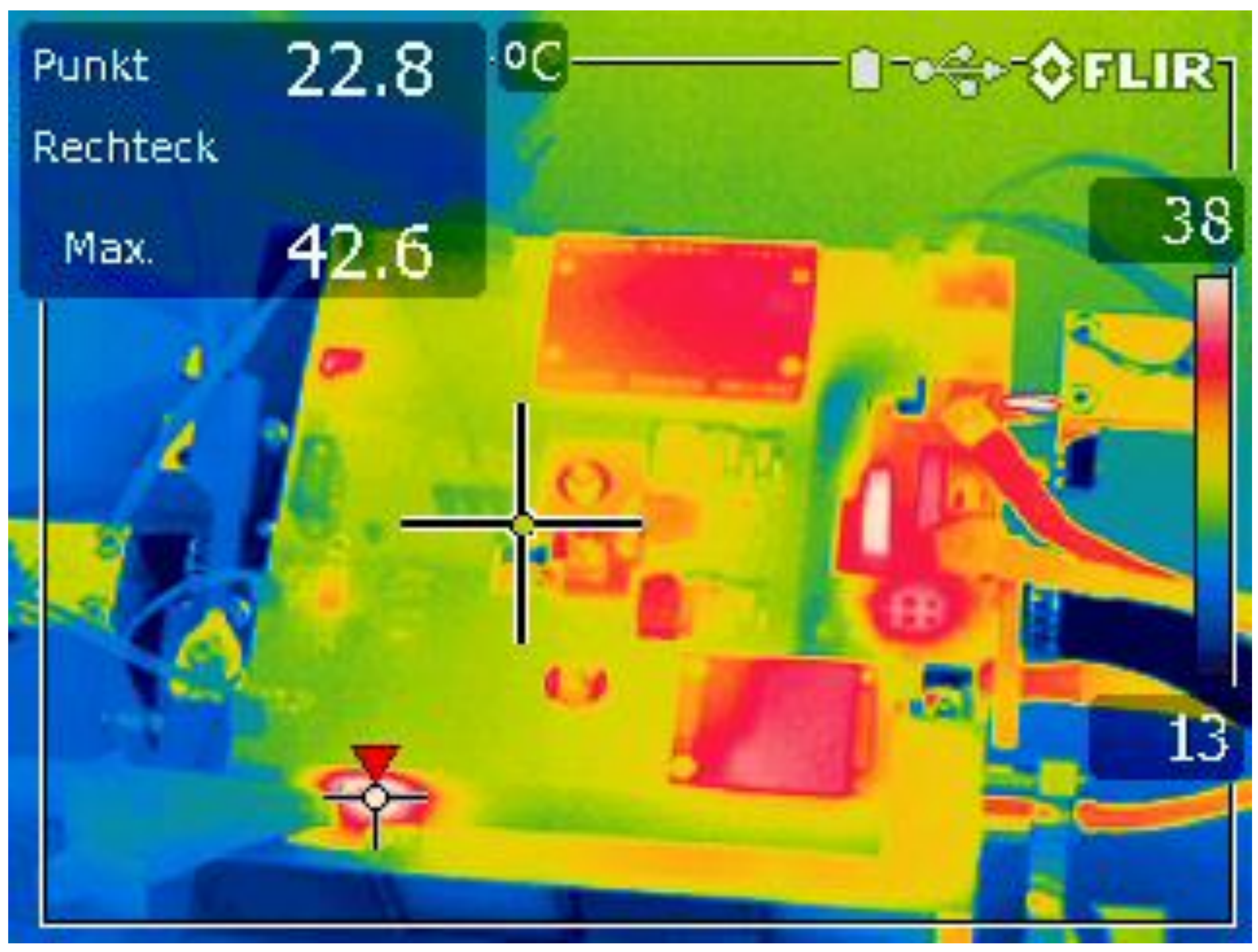

Fig. 9 Thermal camera image of the prototype at full power

- PSU voltage is set to ± 270 V and total TN voltage is 1600 V.
- Total power of 44.83 kW at 83 A phase current.

Conclusions

- Operation at full output voltage of 1600 V and 83 A phase current is verified.
- Phase current is limited by the temperature of the inductor coil.
- Volumetric power density of 11.86 kW/l.
- Mass power density of 10.18 kW/kg.