International Conference on DC Microgrids

Novel Device for Fast Detection and Limitation of Short-Circuit Currents in LVDC Grids

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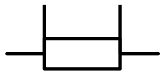
INTRODUCTION

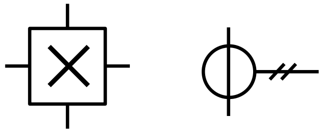
Challenges for switching off at **minimal short-circuit current**

Fast current measurement

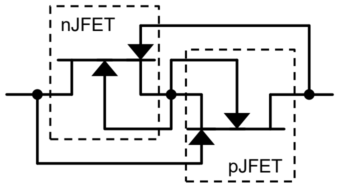
- Intrusive



- Non-intrusive



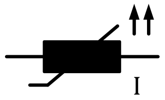
- Intrinsic



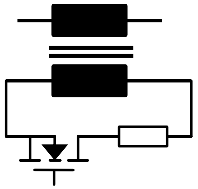
Limiting of current rise

- Passive

- Passive nonlinear



- Active

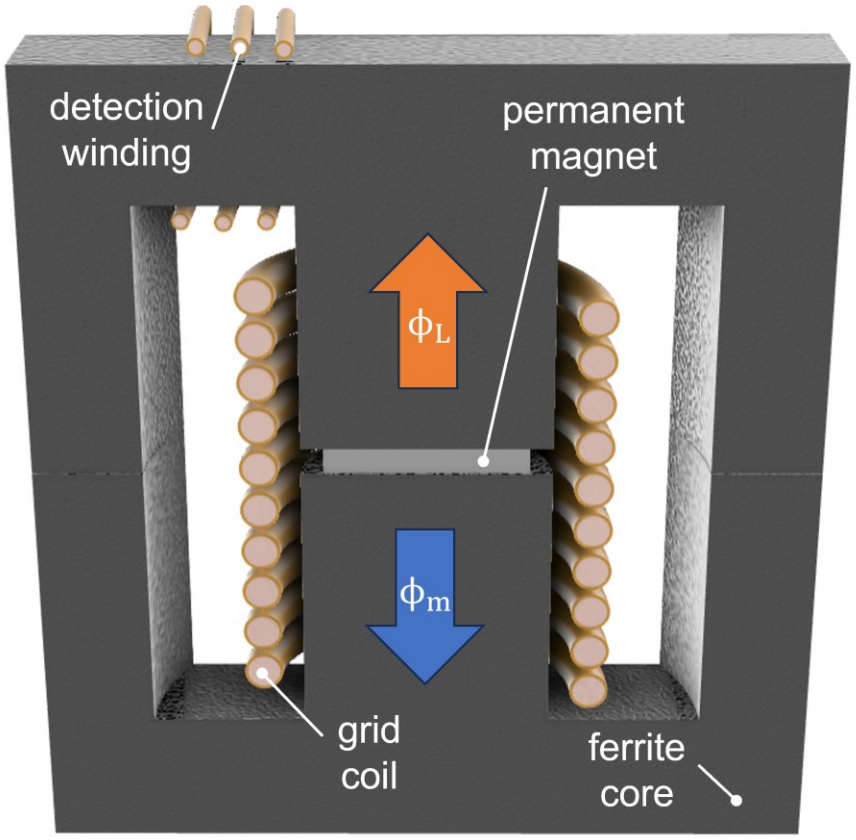


Overcurrent Detection and Limiting Unit (ODLU)

Basic Concept

Transformer with core that is **saturated** in normal operation

- ETD ferrite core
- Saturation by integrating a **permanent magnet** in air gap
- Grid coil in winding window
- Additional detection winding
- **Polarity** of magnet so that the flux caused by the magnet ϕ_m is **counteracting** the flux of the grid-side coil ϕ_L



Basic Concept

Fully saturated core in non-fault operation

Resulting flux

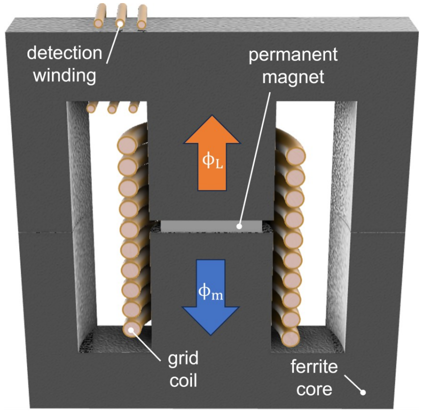
- Non-fault operation:

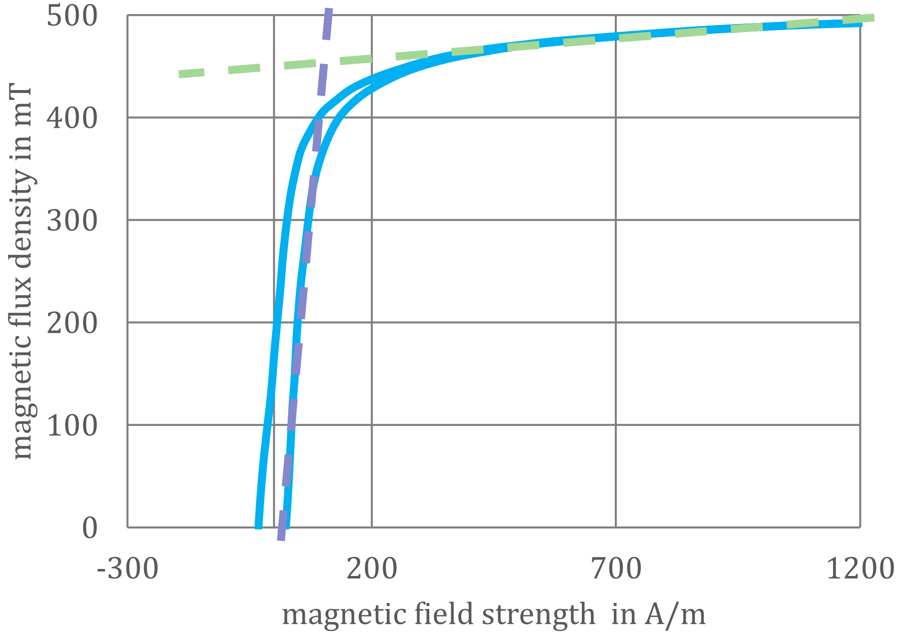
  $\phi_{res} = \phi_m - \phi_L \geq \phi_{sat}$

- Short-circuit fault (threshold current exceeded):

  $\phi_{res} = \phi_m - \phi_{L,th} \leq \phi_{sat}$

  → inductance increases significantly
  → current rise limitation





Magnetic Behavior

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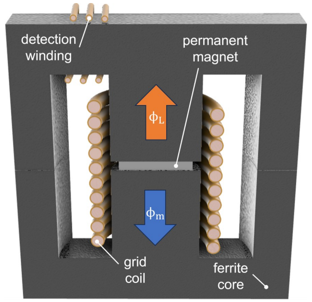
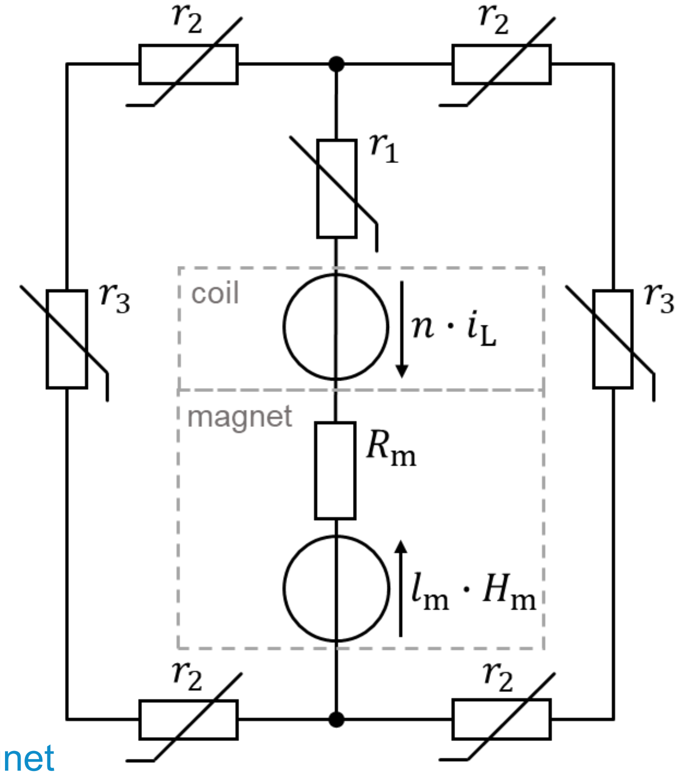


Equivalent magnetic circuit

- Coil and permanent magnet represented by **magnetomotive force**
- Magnetic reluctance of magnet
- Geometry of core is represented by **magnetic reluctances**



Total magnetic reluctance: $$r_{tot} = R_m + r_1 + \frac{1}{2}(2 \cdot r_2 + r_3)$$

Magnetic flux in middle limb: $$\phi_{res} = \frac{n \cdot i_L - l_m \cdot H_m}{r_{tot}}$$

Inductance of grid coil: $$L_{grid} = \frac{n^2}{r_{tot}}$$

Factor **change of inductance:** $$K = \frac{L_{sc}}{L_{nom}} \approx 1 + \frac{r_1 + r_2 + \frac{r_3}{2}}{R_m}$$

thin magnet

Magnetic Behavior

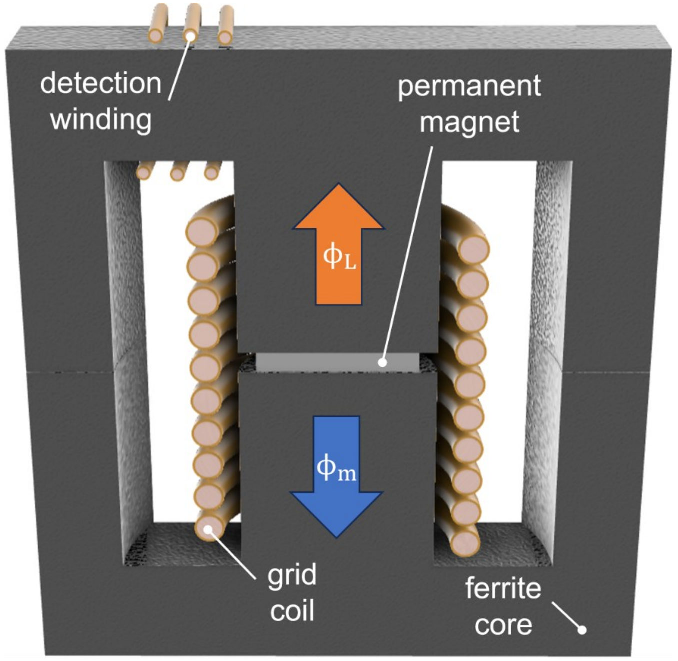
Detection winding

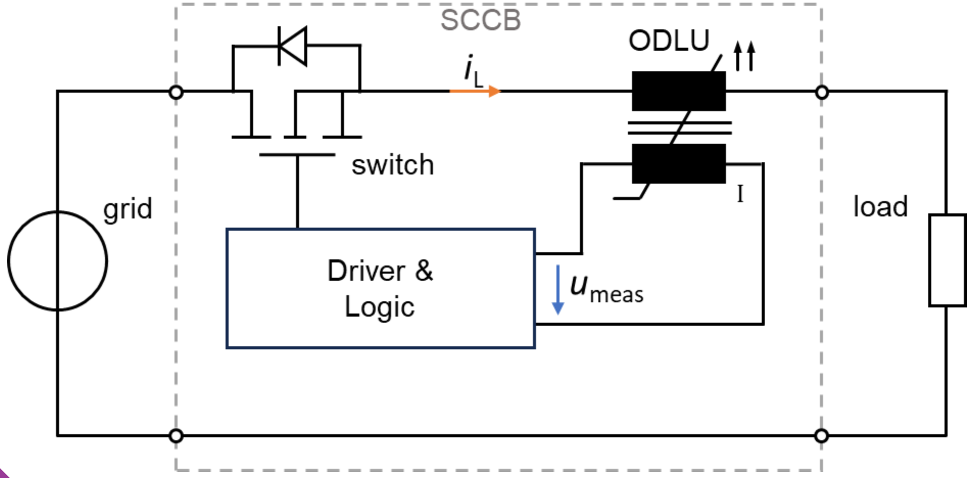
- Utilizes change in core permeability
- Induced voltage increases $$u_{\text{meas}} = \frac{n}{2} \cdot \frac{d\phi_{\text{res}}}{dt}$$
- Proper placement important

Signal can be **directly** fed into a logic circuit

No additional processing unit

Similar aging behavior as a fuse (reliability)





Simulation of Desaturation

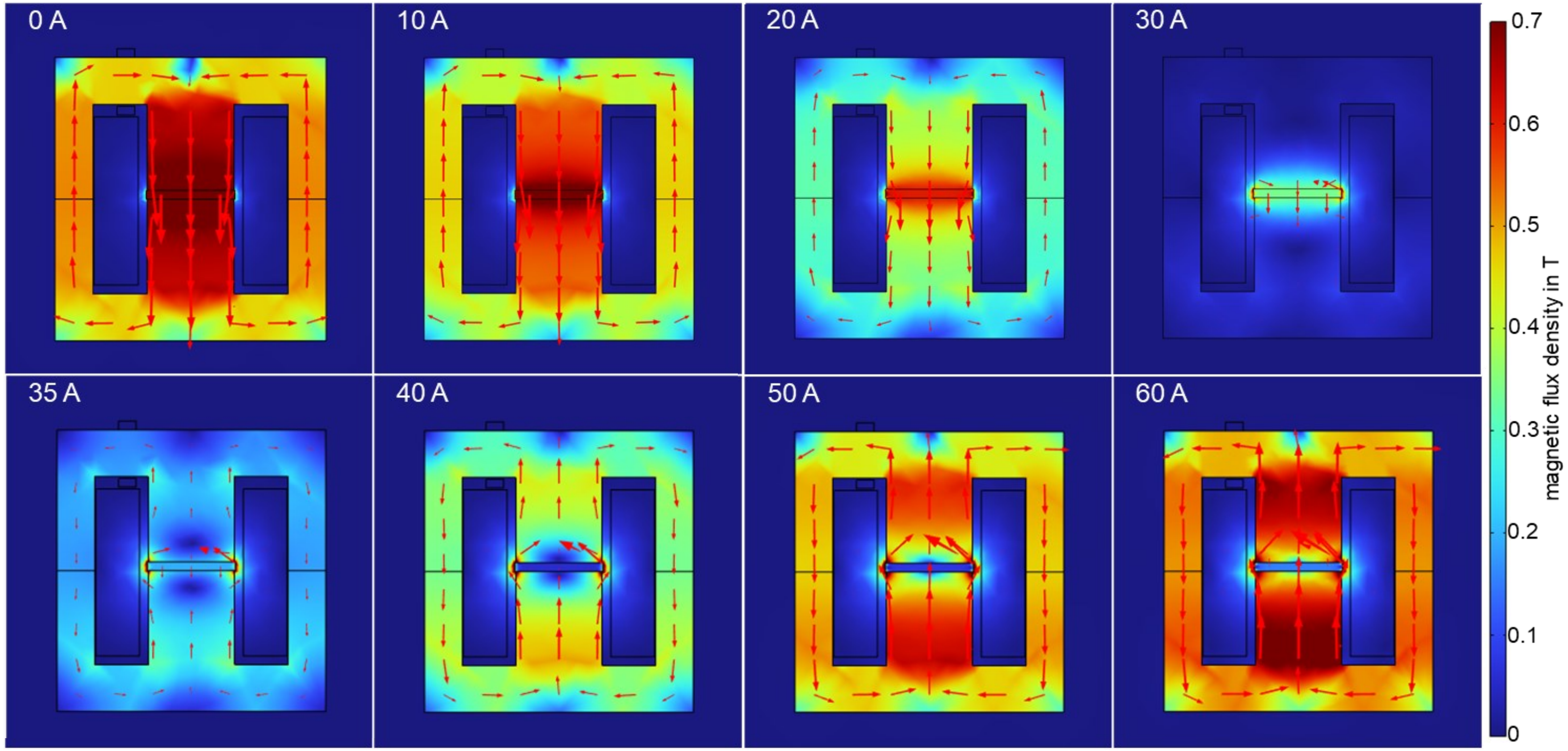
Finite-elements analysis

- Complete **desaturation** at 30 A
- Maximum change rate at 23 A
- Above 50 A **again** fully saturated

Simulation Parameter	Value
Coil windings	11
Ferrite core	ETD 29
Ferrite material	N87
Saturation flux density	450 mT
Magnet thickness	1 mm
Magnet material	N35

Required detection time depends on both current thresholds:

$$t_{\mathrm{dt}} = \left(i_{\mathrm{L,th2}} - i_{\mathrm{L,th}}\right)\frac{L_{\mathrm{sc}}}{U_{\mathrm{grid}}}$$



Number of windings adjusts inductance and threshold

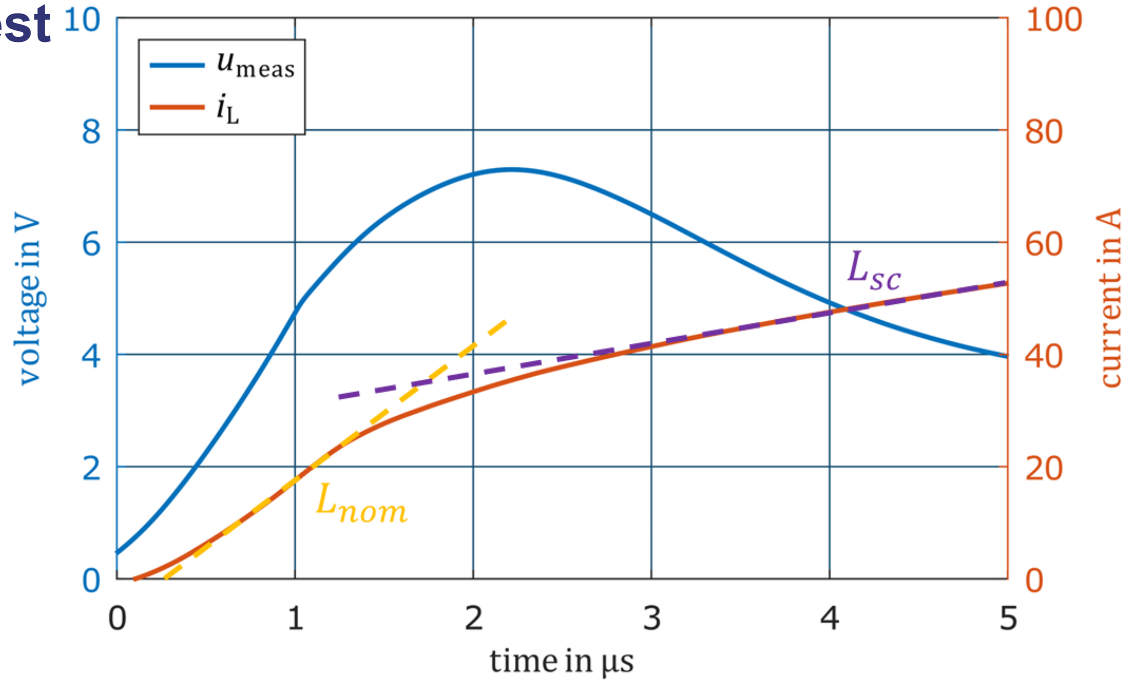
PROTOTYPE LABORATORY TESTS

Prototype has been characterized

Constant voltage applied to input terminals

- Inductance changes from L_{nom} **2 µH to** L_{sc} **10 µH** in short-circuit operation (factor 5)
- Maximum change in inductance at approximately 32 A
- Voltage across the detection coil reaches its **highest value** at nearly the same current of 34 A
  → Suitable for triggering a semiconductor switch

Design Parameter	Value
Nominal current	10 A
Maximum detection voltage	8 V
Grid coil windings	11
Detection coil windings	1
Ferrite core	ETD 29
Ferrite material	N87
Magnet thickness	1 mm
Magnet material	N35



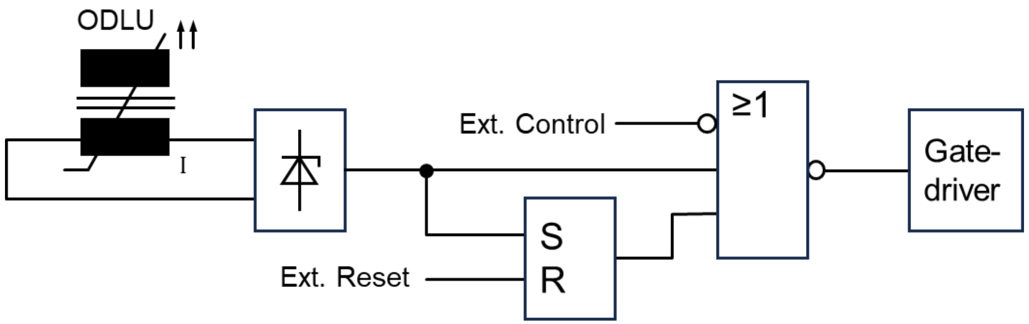
Prototype Laboratory Tests

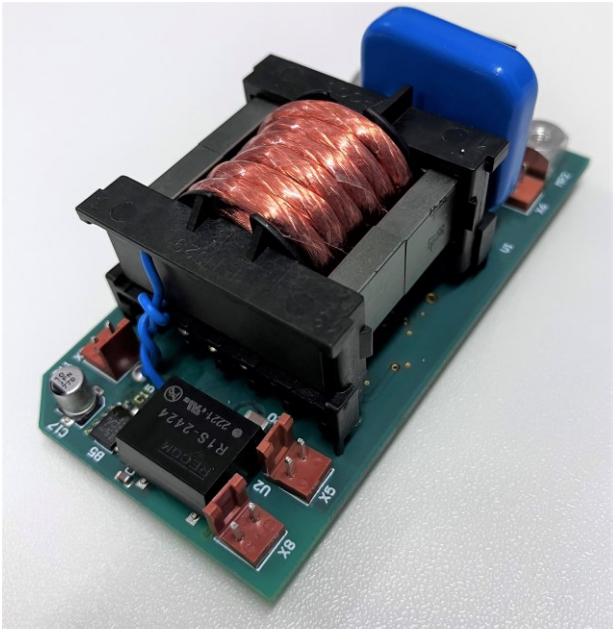
Additional inductive load for switch determined

- **Energy-equivalent inductance** changes only from 2 µH to 4 µH

Complete prototype of a SCCB was built

- Set-reset (SR) bistable element to ensure that the switch **remains open**
- External inputs for control and reset
- Protection from reverse- and over-voltages
- Realized with a SiC-MOSFET for up to 800 V grid voltage

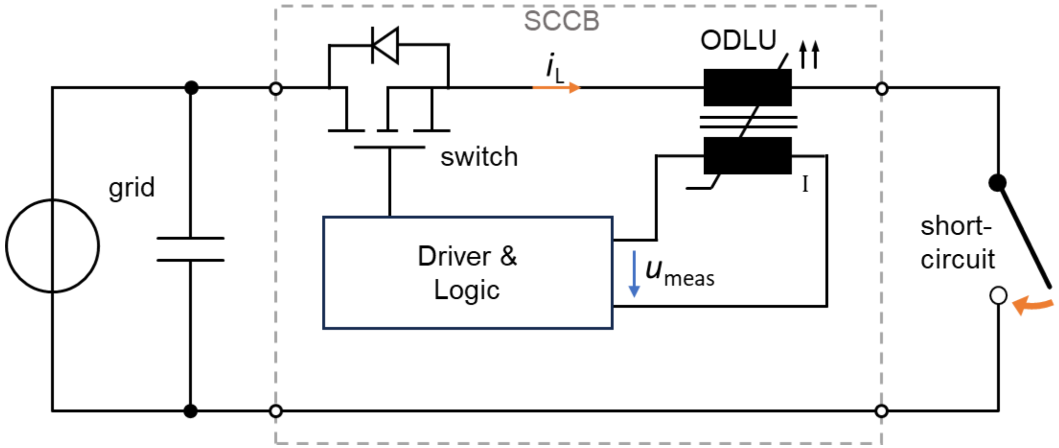


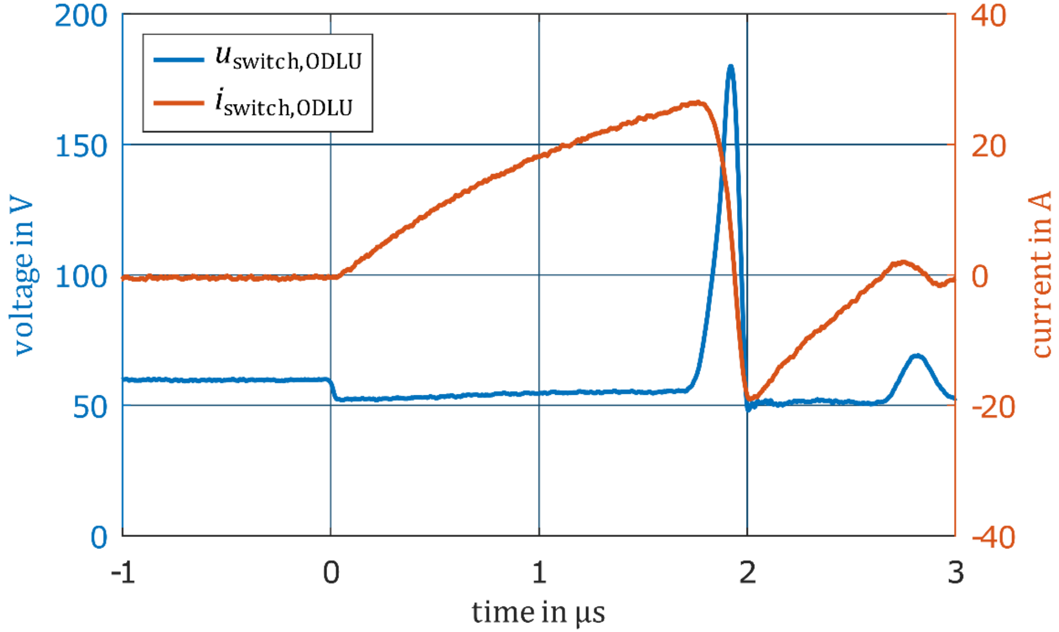


Prototype Laboratory Tests

Prototype was tested with a short-circuit at 60 V in capacitive grid

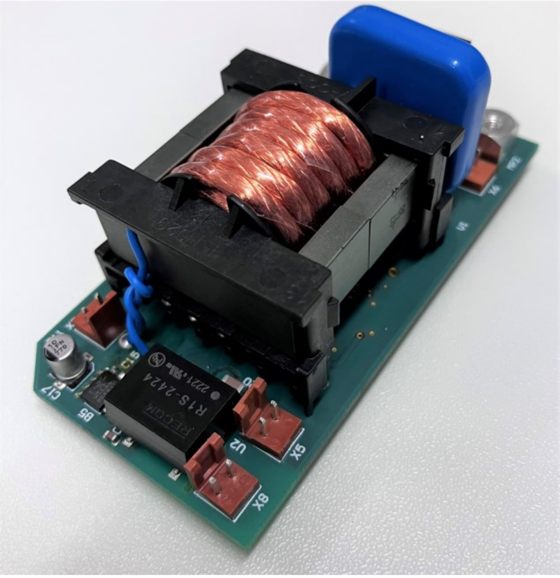
- Threshold at 25 A
- After **15 ns** the gate driver begins to discharge the gate
- Due to the inductively stored energy, the **switching process** takes around **200 ns** from exceeding the threshold **including the detection time**





Conclusion And Further Work

ODLU is a promising solution for managing short-circuit currents in DC grids.
The hardware-based **fast** and **galvanically isolated** detection signal further enhances its applicability in semiconductor circuit breakers.



First results of the ongoing experiments demonstrate the device's effectiveness.
A **reaction time of 15 ns** was achieved and an **interruption time of 200 ns** at
60 V. Further tests will be performed with **voltages up to 800 V** and a **current threshold of 100 A**.