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FORSCHUNGSCAMPUS FLEXIBLE ELEKTRISCHE NETZE







Forschungscampus Flexible Elektrische Netze FEN

February 15, 2024

Disconnectable DC-Link Capacitors for DC-Grid Protection

Challenges of DC-Fault Interruption

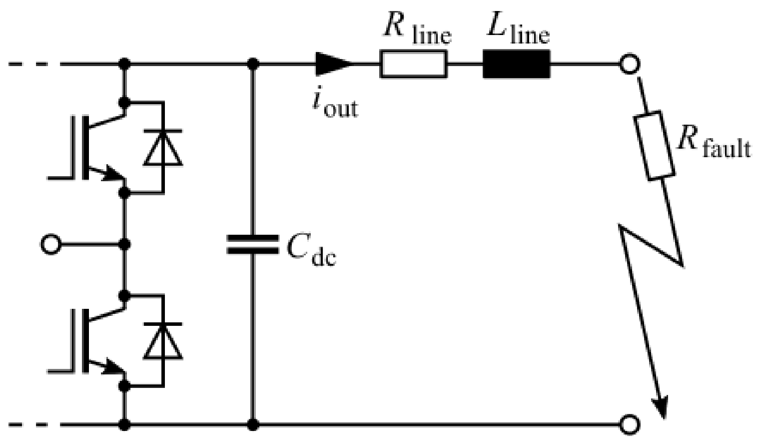
- DC-faults have two phases
  I. Fault current build up
  II. Fault current decay

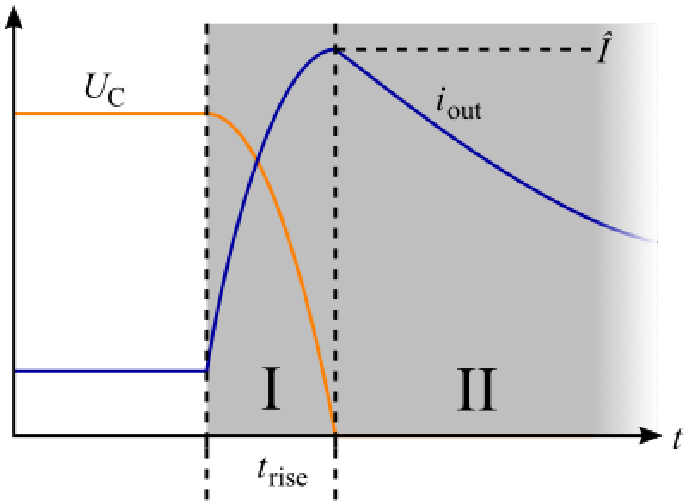
- Unlike ac faults, time interval I is mostly limited by line reactance
  – For short distances, fault current can reach very high values

  – Exemplary 5 kV grid: $\hat{I} \approx \sqrt{\frac{C_{dc} U_C^2}{L_{line}}} \rightarrow \sqrt{\frac{9\ \text{mF} * 5000\ \text{V}^2}{50\ \mu\text{H}}} \approx 67\ \text{kA}$

- Fault current rise time is also limited by line reactance
  – For short distances, fault current rise can be the significant challenge for interruption

  – Exemplary 5 kV grid: $t_{rise} \approx \frac{\pi * \sqrt{C_{dc} L_{line}}}{2} \rightarrow \frac{\pi * \sqrt{9\ \text{mF} * 50\ \mu\text{H}}}{2} \approx 1.05\ \text{ms}$

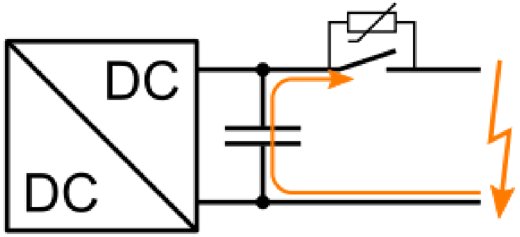




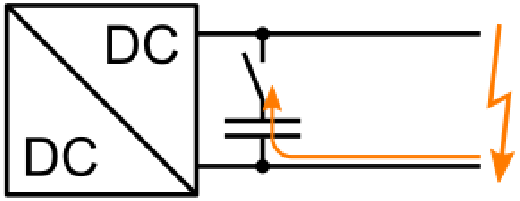
DC Grid Fault-Current Handling

- Three different fault current handling variants

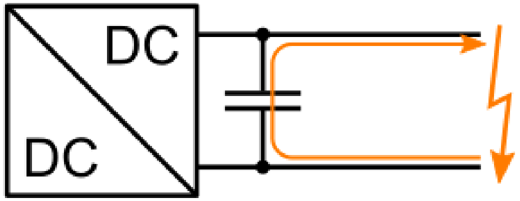
- In-line dc circuit breaker
  - Hybrid or solid-state
  - Needs to carry full current



- Disconnectable dc-link capacitor
  - Disconnects dc-link from line during fault
  - Carries only dc-link ripple current



- Freely circulating fault current
  - No breaker
  - Full fault current



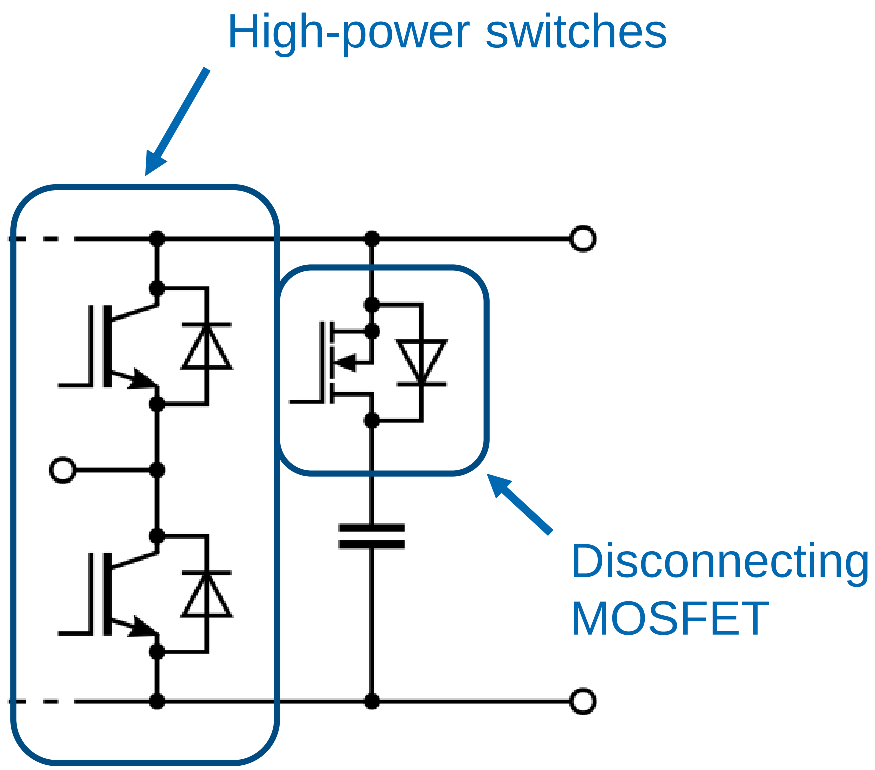
Disconnectable DC-Link Capacitors

- Disconnecting dc-link during a fault to
  - Avoid excessive fault currents (no capacitor discharge)
  - Fast grid restoration after fault (no capacitor recharge)

- Additional switch needed
  - Bidirectional power flow
  - Carriess only ripple current
  - For LVDC, MOSFETs are a promising option

- Low turn-off times for disconnecting switch
  - Disconnecting switch cannot handle full fault current
  - Fast fault-current interruption in low µs range

- Extension of State-of-the-Art
  - Disconnectable storage elements for MMCs proposed by Marquardt
  - Patent US 2018/0109202 , granted in 2023



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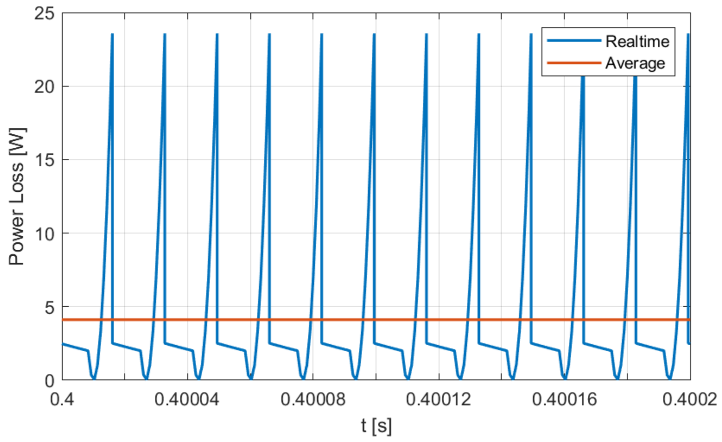
Power Loss during Normal Operation

- Disconnecting switch only carries capacitor ripple current during normal operation
  – 3 phase dual-active bridge (DAB3) features low ripple current
  – Other topologies with low ripple current also suitable
- Overall power loss negligable in comparison to converter power
  – 100 kW converter power at 800 V
  – 4 W losses in total for all disconnecting switches
  – Ripple current mostly independent from dc-link capacitance
- Concept is feasible for application
  – Power loss can be cooled by convection
  – Integration into dc-link capacitor possible

Parameter	3ph DAB
DC-Link Voltage	800 V / 800 V
Output Power	100 kW
Switching Frequency	10 kHz
Leakage Inductance	30 µH
Phase Shift (Pmax)	28°
Output Capacitor	6 x 50 µF
Switch Resistance	48 mΩ (6 of)



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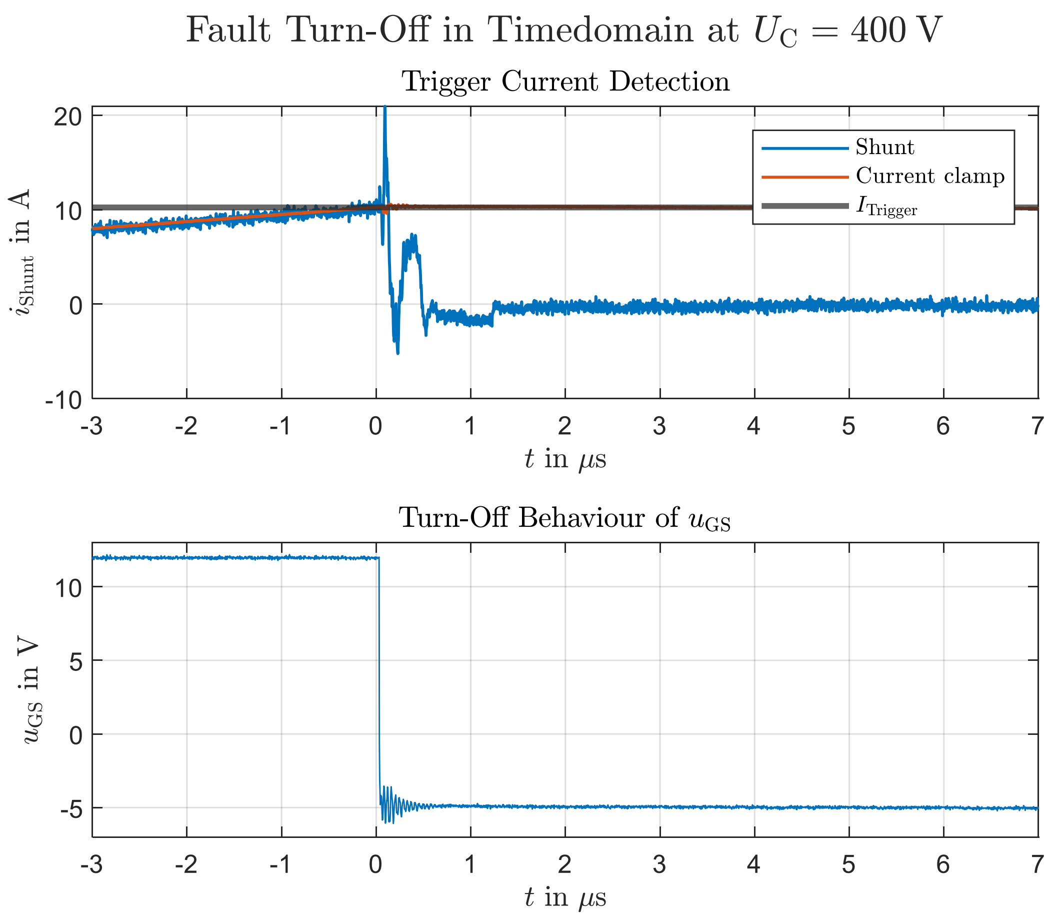
Experimental Results

- Prototype PCB to check fault interruption
  - 400 V rated voltage
  - SiC MOSFET as disconnecting switch
  - Half-bridge IGBT module for commutation
- First test with varying dc-link voltage and 600 µH current-limiting inductance
  - Trigger current of 10 A
- Fault current measured by 5 mΩ shunt
- Switching overvoltage below 100 V



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Vielen Dank für Ihre Aufmerksamkeit!

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