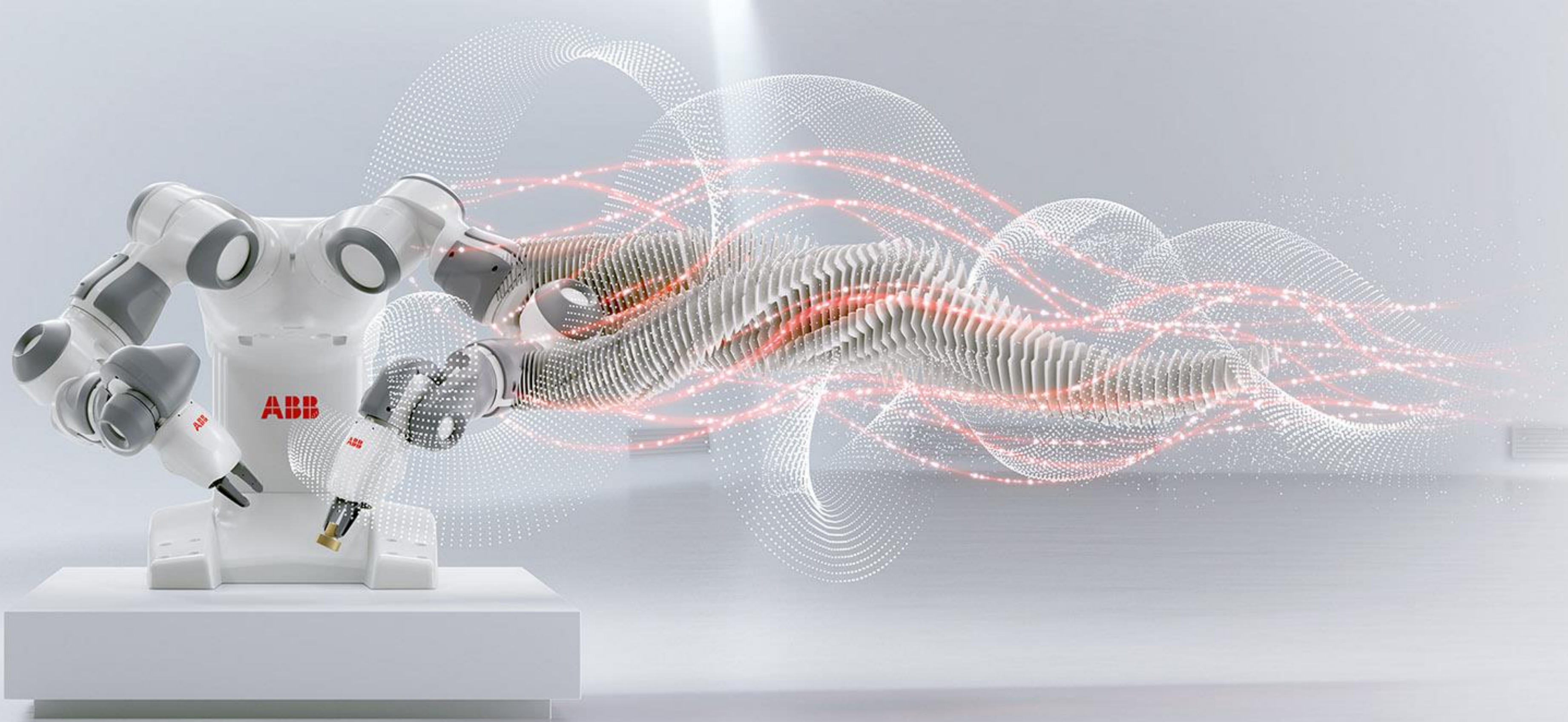


APRIL 12, 2019

Fast Circuit Protection

For DC & more-DC Systems

Debrup Das

Presentation Overview

System trends: Need for faster breakers

Increased Arc Voltage Interruption

Current Injection (with Pre-charged Capacitor)

Resonance Current Injection (No Pre-charge)

Hybrid Interruption (Arc-less)

Solid State Circuit Breaker

ABB Innovation: Switch on the future

System Trends – Needs for Faster Breakers

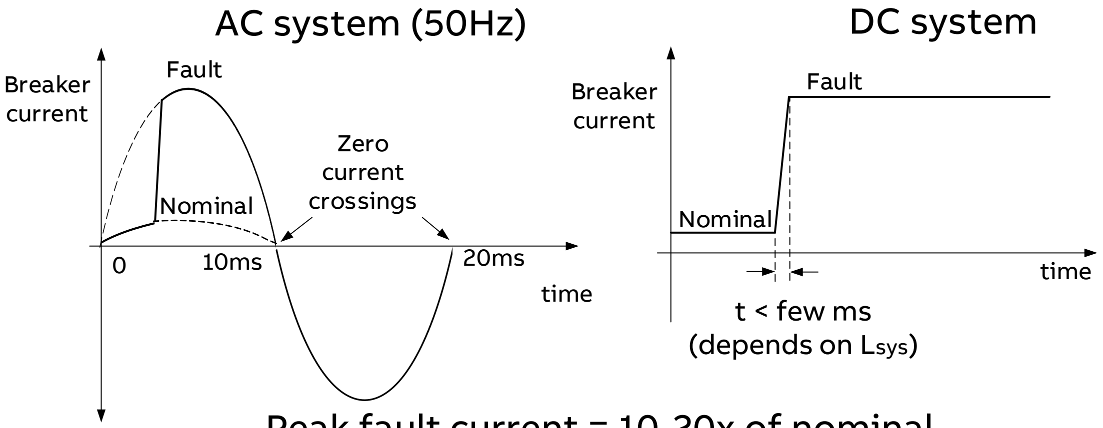
Emerging DC & more-DC systems

Native and more-DC systems

- PV systems
- Datacenters
- Energy storage systems
- DC ships
- Electric vehicle charging infrastructure

Challenges in DC protection

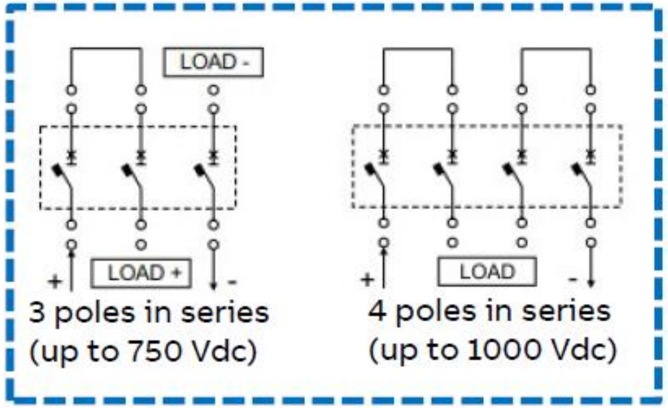
- No natural zero-crossing (unlike AC systems)
- Delay in action results in higher fault current that becomes increasingly difficult to break
- Natural system inductances may be limited



Peak fault current = 10-20x of nominal

Increased Arc Voltage Interruption

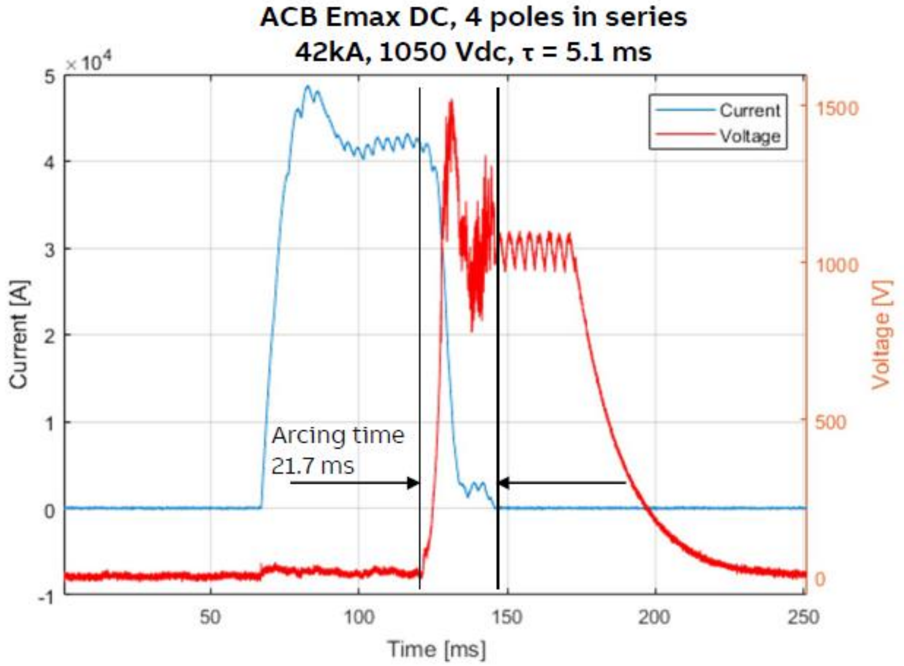
Achieving higher arc voltage



Pros
- Simple and low cost concept
- Low loss

Cons
- Large arc energy and time
- Difficult to scale
- Contacts wear

DC current interruption



Current Injection (with Pre-charged Capacitor)

Specifications

Based on 3 pole AC vacuum circuit breaker built and tested

- One pole for current interruption
- One pole for current injection
- One pole as disconnector

Ratings

- U_{NOM}=12kV
- I_{NOM}=2.5kA
- $I_{INTERRUPTED}$=15kA

Pre-charged capacitor for current injection

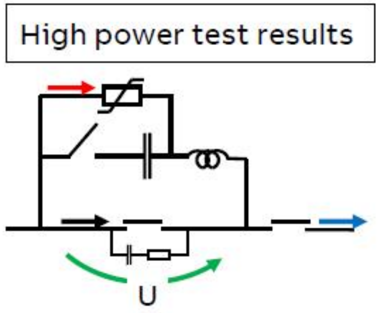
Commutation of current between three branches

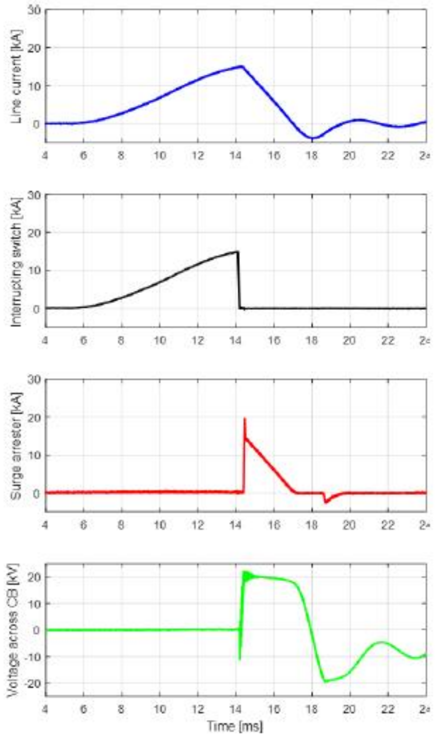
Current finally interrupted by the surge arrester

Pros
- Simple and low cost
- Low loss

Cons
- Large arc energy and time
- Difficult to scale
- Contacts wear

Prototype and results

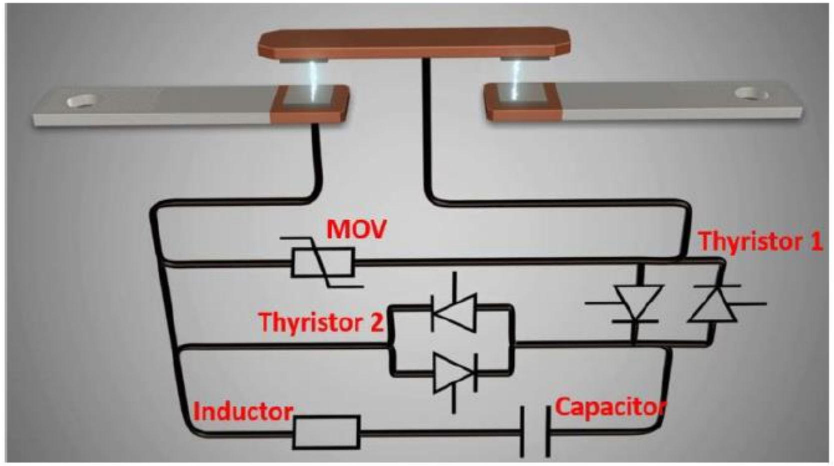




Source: L. Liljestrand, M. Backman, L. Jonsson, E. Dullni, M. Riva, "Medium voltage DC vacuum circuit breaker", International Conference on Electric Power Equipment – Switching Technology (ICEPE-ST), 2015

Resonance Current Injection (No Pre-charge)

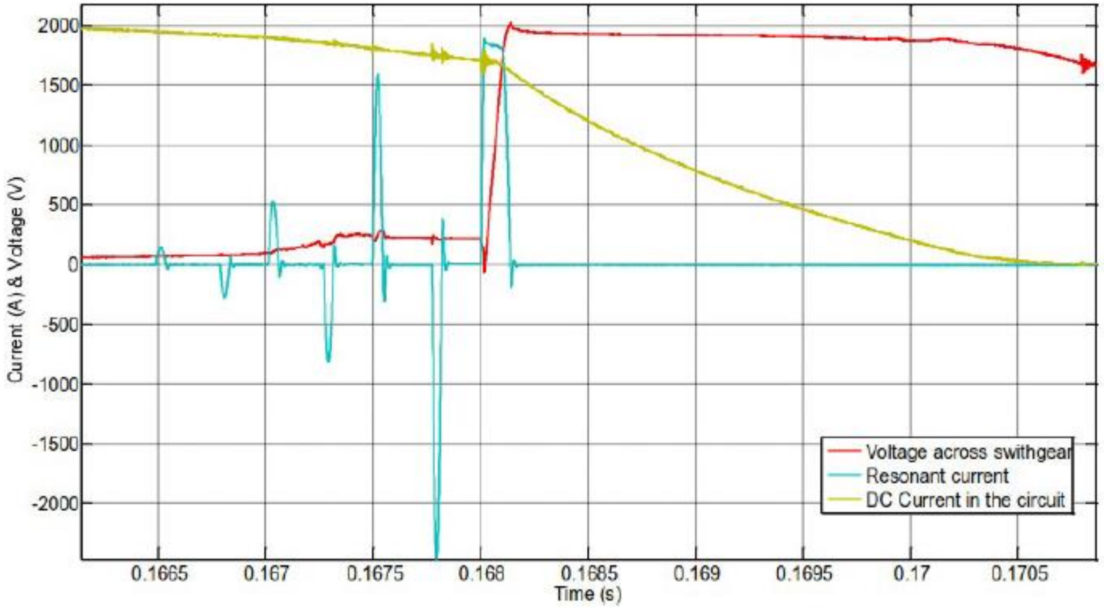
Conceptual circuit



Pros
- Simple concept
- Scalability
- Low loss

Cons
- Medium arc energy and time
- Limited short-circuit capacity
- Limited speed by mechanical switch

Test results



2000 A, ~1800 VDC interruption in ~8 ms

Source: Z. Zhang, S. Valdemarsson, et al, "A novel low voltage hybrid DC switch using resonant current injection" COSYS-DC 2017, International conference on Components and systems for DC Grids, Grenoble 2017

Hybrid Interruption (Arc-less)

Specifications

Based on IGBT switches for current interruption in parallel with main current carrying fast mechanical switch

Ratings

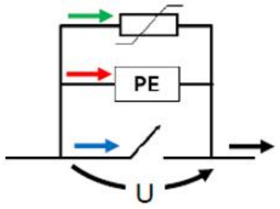
- System voltage 12kV
- Nominal current 2kA
- Short-circuit current 25kA
- Maximum limited current peak 13kA
- Trip level 5.6kA
- Time from trip to bypass contact opening 0.35ms
- Time from trip to power electronics turn-off 0.7ms

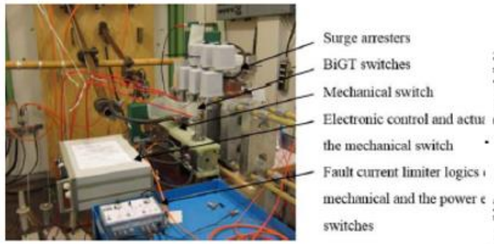
Pros
- Simple concept
- Low loss

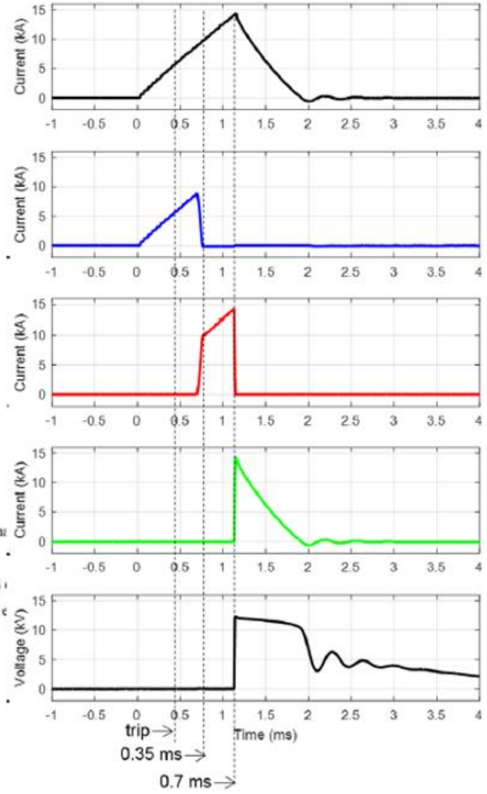
Cons
- medium arc energy and time
- Limited short-circuit capacity

Prototype and results

High power test results





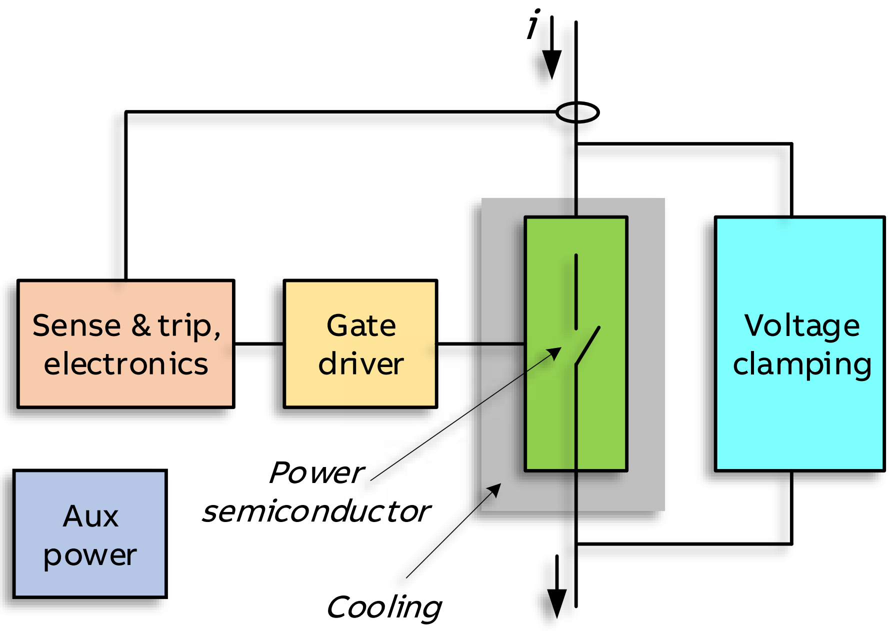


Source: L. Liljstrand, L. Jonson,M. Backman, M. Riva, “A new hybrid medium voltage breaker for DC interruption or AC fault current limitation” ECCE Europe 2016

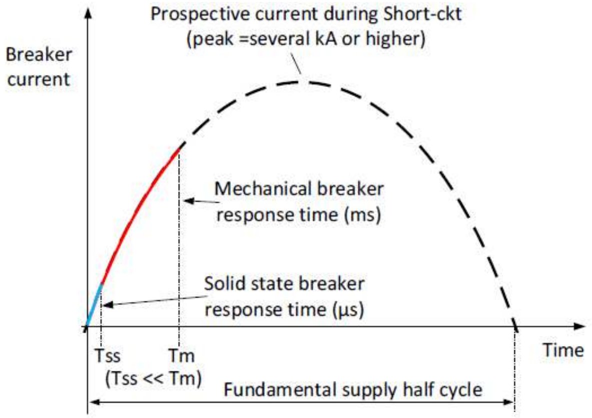
Solid State Circuit Breaker

Key elements & benefits

Key elements of SSCB

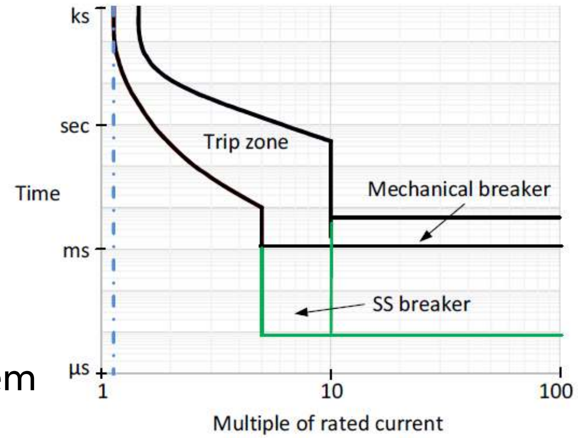


Key performance aspects



Time-domain

- Ultra-fast fault interruption
- Arc-less switching
- Reduced let through energy
- Reduced fault-stress on system



i*t trip curve

Source: R. Rodrigues, T. Jiang, Y. Du, P. Cairoli, H. Zheng, "Solid State Circuit Breakers for Shipboard Distribution Systems," *IEEE Electric Ship Technologies Symposium (ESTS)* 2017, Arlington VA, USA

Solid State Circuit Breaker

Device selection

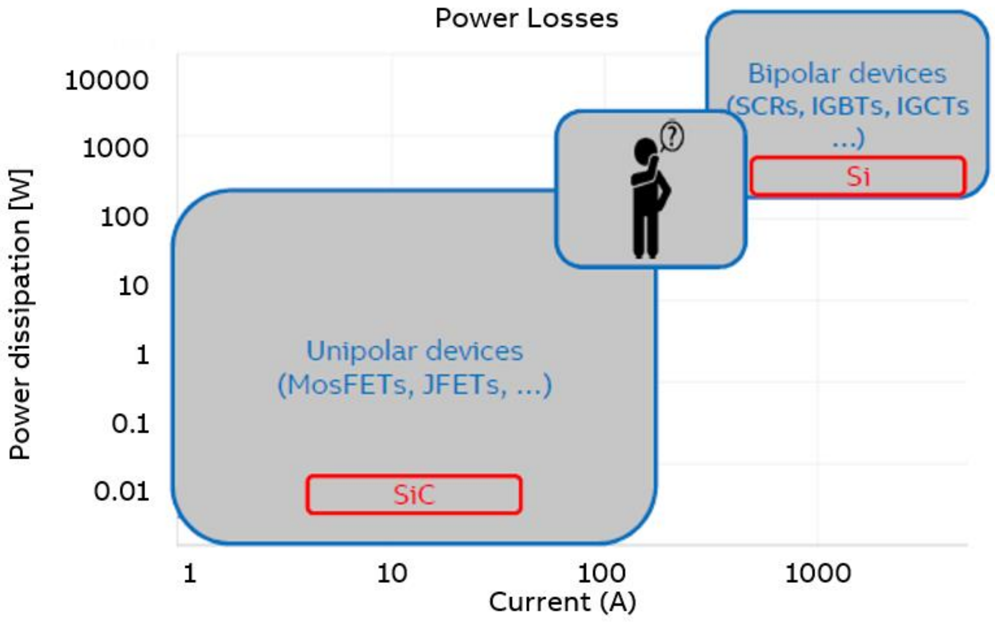
Device selection

In event switching devices, switching losses are not relevant

$$P_{loss} = P_{on} + \cancel{P_{switch}}$$

$$P_{loss} = \begin{cases} R_{on}(i,T)\,i^2 & \text{Unipolar devices (JFETs, MosFETs ...)} \\ V_T(i,T) \times i & \text{Bipolar devices (SCRs, IGCTs, IGBTs ...)} \end{cases}$$

Primary selection criteria

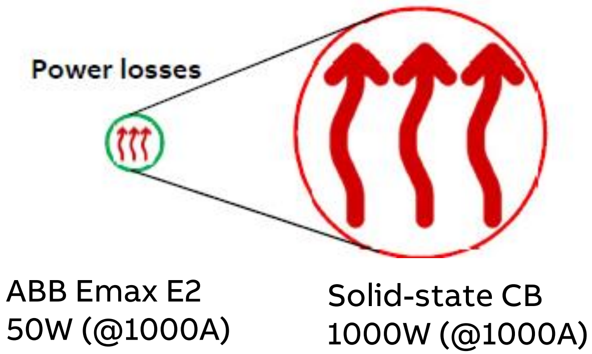


Si vs WBG
Unipolar vs Bipolar
Normally-on vs Normally-off

Solid State Circuit Breaker

Cooling

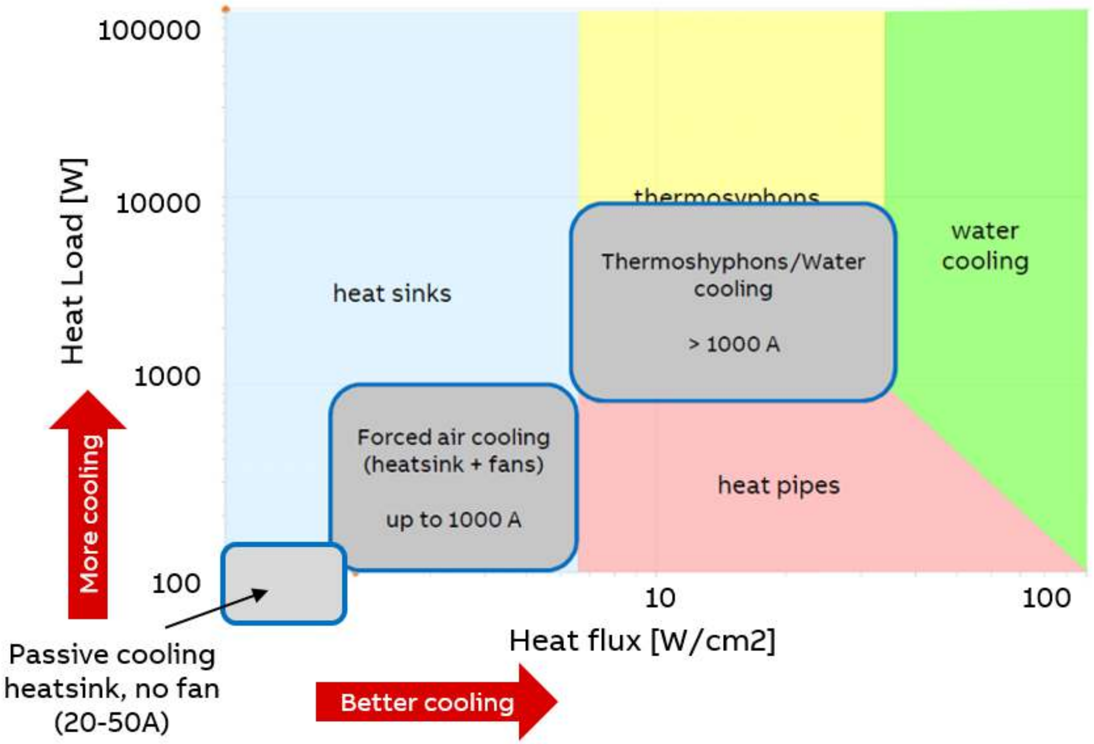
Mechanical vs Solid-state



Electromechanical breakers
- Busbars and wiring are enough to dissipate the power loss

Solid state switching devices
- Needs additional cooling

More cooling vs better cooling



Solid State Circuit Breaker

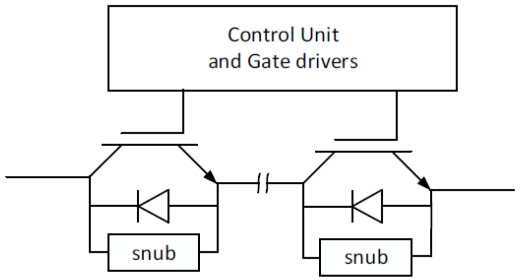
Recent Trends & Literature

IGBT based MV breaker

Series connection

Fast switching

Higher losses

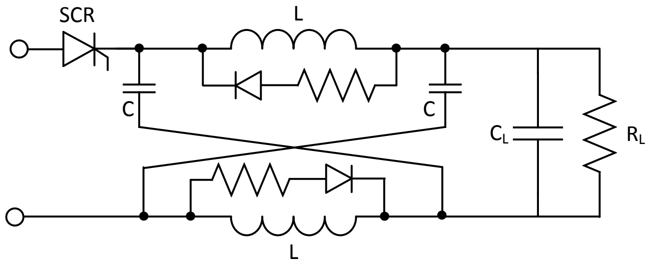


Z-source Thyristor based breaker

Lower losses

Resonance commutation

Large passives

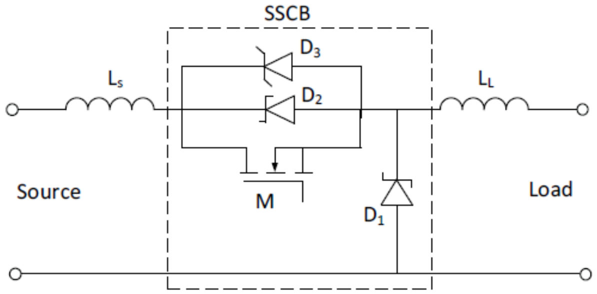


SiC MOSFET based breaker

Low losses

Ultrafast switching

Thermal challenges

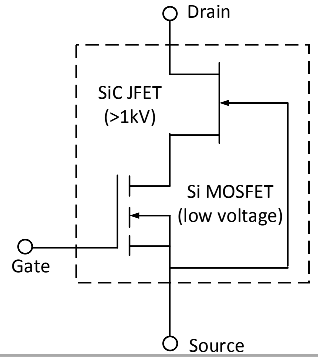


SiC JFET cascode breaker

Low losses

Ultrafast switching

Additional LV Si MOSFET in series



<u>Source</u>: R. Rodrigues, T. Jiang, Y. Du, P. Cairoli, H. Zheng, "Solid State Circuit Breakers for Shipboard Distribution Systems," *IEEE Electric Ship Technologies Symposium (ESTS)* 2017, Arlington VA, USA

Solid State Circuit Breaker

380Vdc, 20A

Specifications

Nominal rating

– 400V DC, 10-20A

Switching unit

– 4x30mΩ, 1200V MOSFETs

Interruption speed

– few µs

Short-circuit capability (perspective current)

– unlimited

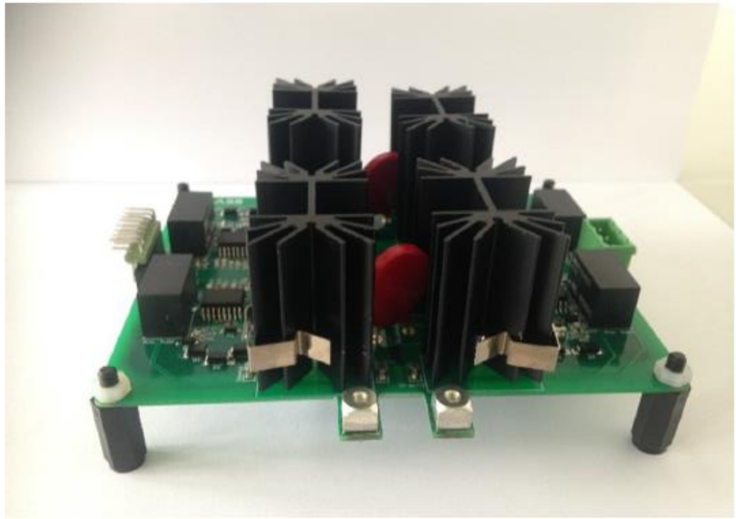
Power Loss

– 12W, passive air-cooling

Sense and Trip

– Current measurement and high-speed microprocessor

Prototype



Power Solid State Circuit Breaker

1kVdc, 1.5kA

1kV 1.5kA SS DCCB

Solid-state DC circuit breaker based on cutting-edge technology

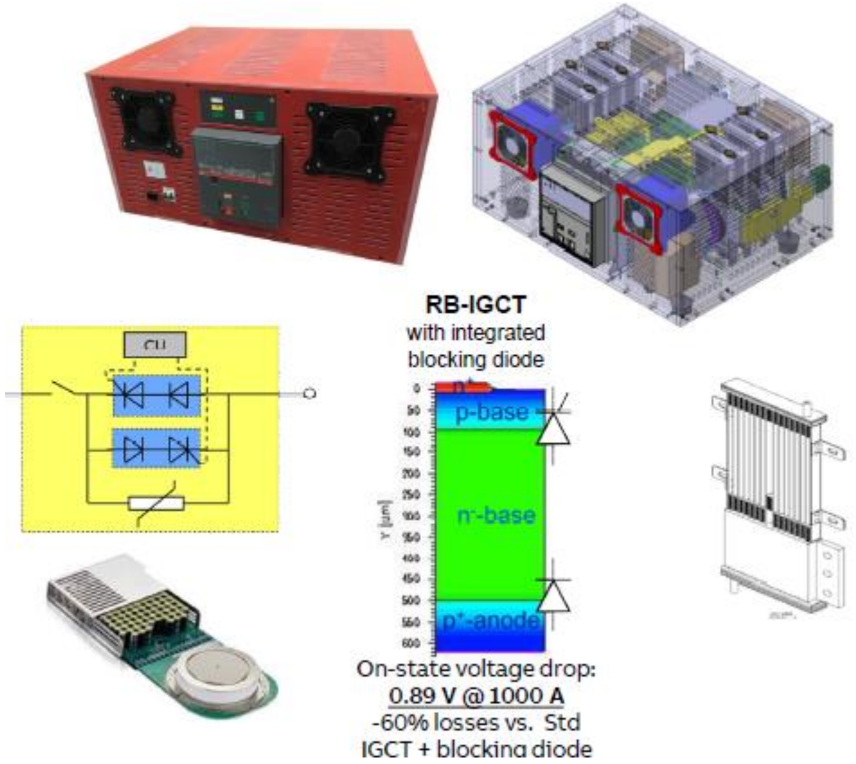
- Low-losses(V_T<1V) RB-IGCT(2.5kV) optimized for event-switching
- Air cooling based two-phases thermosyphons (PHP technology)
- High-speed trip and control unit

Unmatched performances

- Ultrafast <1ms(faster than high-speed fuses!)
- Breaking capacity >200kA prospective (fault current limited to 3-5kA in <1ms)
- 99.7% efficiency

Applications DC ships Dc microgrids, battery energy storage systems (BESS)

Prototype

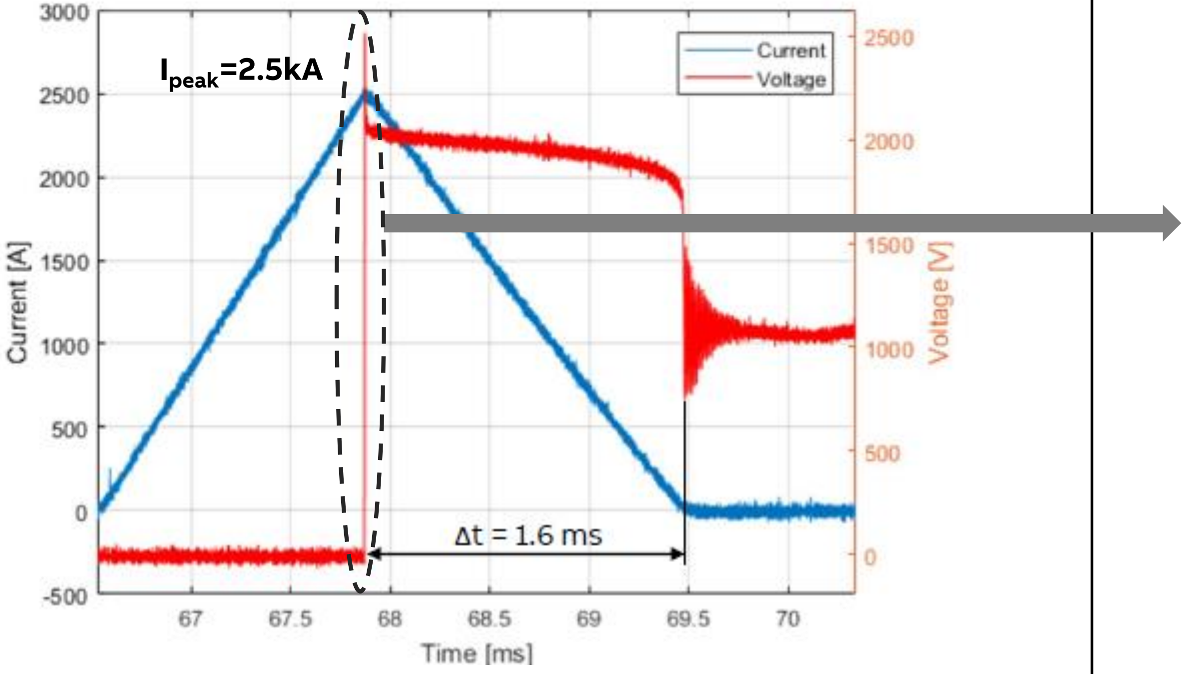


Source: F. Agostini, U. Vemulapati, D. Torresin, M. Arnold, M. Rahimo, A. Antoniazzi, L. Raciti, D. Pessina, H. Suryanarayana, “1MW Bi-directional DC Solid State Circuit Breaker based on Air Cooled Reverse Blocking-IGCT” ESTS 2015

Power Solid State Circuit Breaker

Switching performance

Breaker turn-off waveform



RB-IGCT turn-off

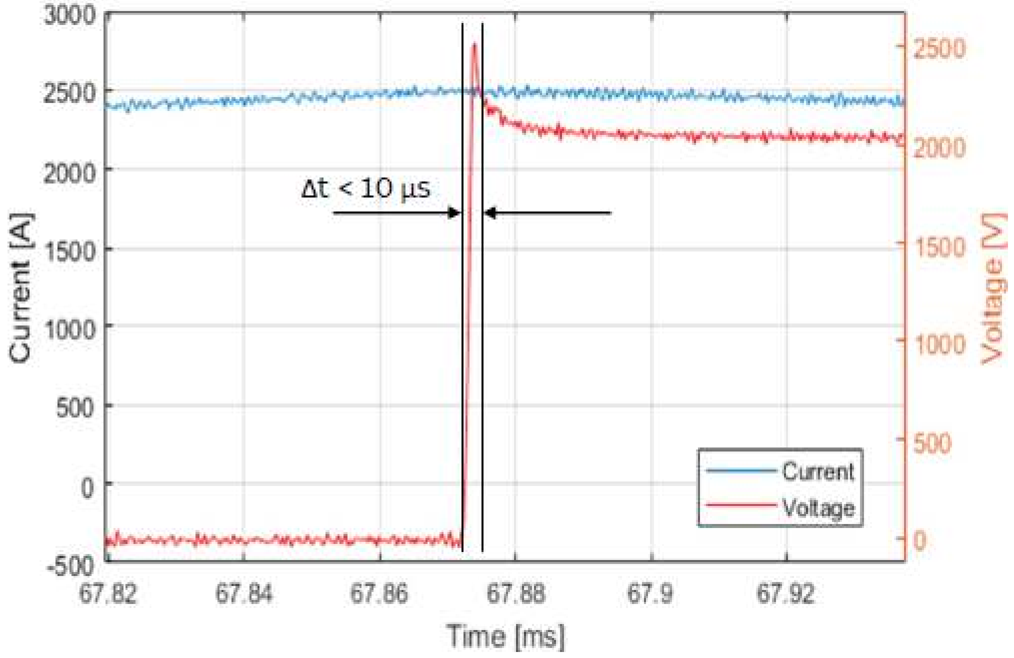


ABB reinvents the circuit breaker

Solid State DC Circuit Breaker

Presented at the Hannover Fair, April 1-5, 2019

Breakthrough features

- Nominal current from 1000 to 5000 A
- Voltage up to 1500 VDC
- Air and water (not deionized) cooling
- Fixed and plug-in versions

Target applications

- DC ships
- DC microgrids
- Battery storage
- Arc-safe solutions
- …

Switch on the future!

ABB