Fast Circuit Protection
For DC & more-DC Systems
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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

ACB Emax DC, 4 poles in series
42kA, 1050 Vdc, τ = 5.1 ms

Arcing time 21.7 ms
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
- \( U_{\text{NOM}} = 12 \text{kV} \)
- \( I_{\text{NOM}} = 2.5 \text{kA} \)
- \( I_{\text{INTERRUPTED}} = 15 \text{kA} \)

Pre-charged capacitor for current injection
Commutation of current between three branches
Current finally interrupted by the surge arrester

Prototype and results

Pros
- Simple and low cost
- Low loss

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

Resonance Current Injection (No Pre-charge)

Pros
- Simple concept
- Scalability
- Low loss

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

Conceptual circuit

Test results

2000 A, ~1800 VDC interruption in ~8 ms

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

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
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Key elements & benefits

Key elements of SSCB

- Sense & trip, electronics
- Gate driver
- Voltage clamping
- Power semiconductor
- Cooling
- Aux power

Key performance aspects

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

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Device selection

Device selection

In event switching devices, switching losses are not relevant

\[ P_{\text{loss}} = P_{\text{on}} + P_{\text{switch}} \]

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

Primary selection criteria

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

Mechanical vs Solid-state

- Power losses
  - Electromechanical breakers:
    - Busbars and wiring are enough to dissipate the power loss
  - Solid state switching devices:
    - Needs additional cooling

- ABB Emax E2
  - 50W (@1000A)
- Solid-state CB
  - 1000W (@1000A)

More cooling vs better cooling

- Forced air cooling (heatsink + fans) up to 1000 A
- Thermosyphons/Water cooling > 1000 A

Heat flux [W/cm²]

More cooling

Heat Load [W]
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Recent Trends & Literature

**IGBT based MV breaker**
- Series connection
- Fast switching
- Higher losses

**SiC MOSFET based breaker**
- Low losses
- Ultrafast switching
- Thermal challenges

**Z-source Thyristor based breaker**
- Lower losses
- Resonance commutation
- Large passives

**SiC JFET cascode breaker**
- Low losses
- Ultrafast switching
- Additional LV Si MOSFET in series

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

Power Solid State Circuit Breaker
Switching performance

Breaker turn-off waveform

\[ I_{\text{peak}} = 2.5 \text{kA} \]
\[ \Delta t = 1.6 \text{ ms} \]

RB-IGCT turn-off

\[ \Delta t < 10 \mu\text{s} \]
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!