DC CIRCUIT-BREAKERS

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CIGRE A3/B3 UK meeting, 15th Jan 2025

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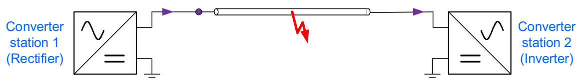
Where/why do we need a DCCB?

Point-to-point schemes

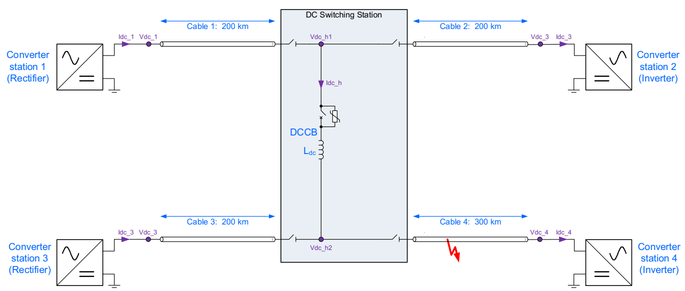
- DC Fault clearing is by:
  - Blocking the IGBTs
  - Opening ACCBs
  - Waiting for trapped DC current to decay
- DCCBs are **not essential**, and difficult to justify



Radial Multi-terminal

e.g. the German “DC switching station” projects

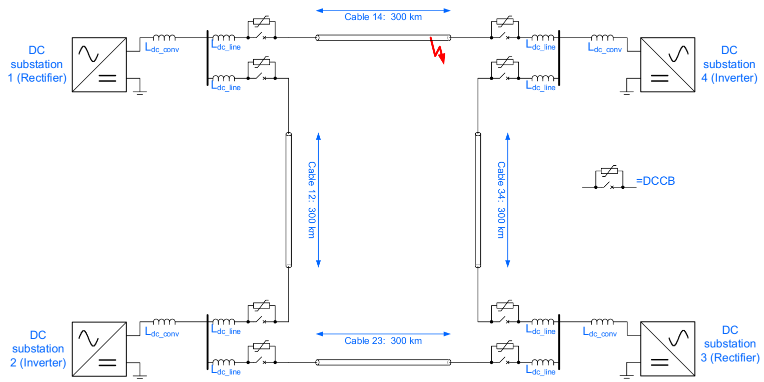
- DCCBs are needed at selected locations to limit the maximum loss of infeed



Meshed DC grid

e.g. the Zhangbei project in China

- DCCBs could be needed at each end of each line
- To isolate only the faulted line



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AC vs DC circuit-breakers

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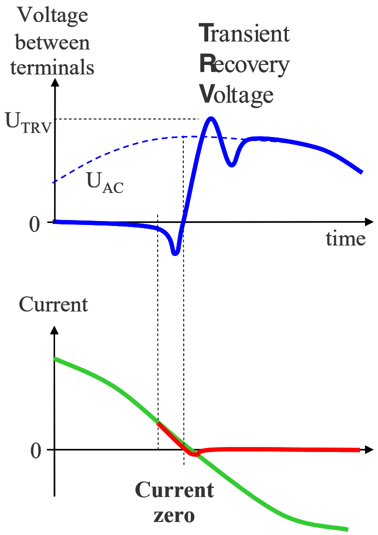
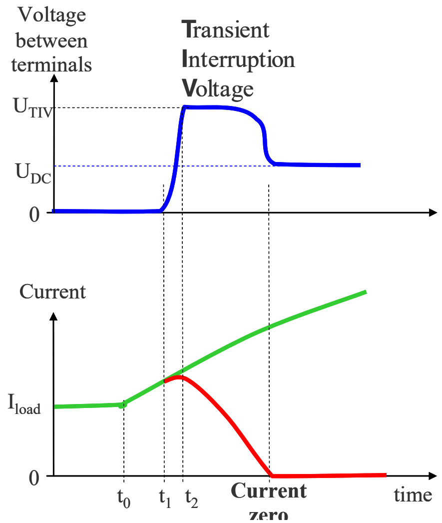
AC circuit-breaker



- Interrupts current at a natural zero
- Multiple opportunities to interrupt
- Well-known, mature technology (>100 years)

DC circuit-breaker



- Has to create its own current zero
- …and absorb the stored energy in inductances (½LI²)
- Current keeps getting bigger and bigger until interruption
- Mature technology up to ~3 kV_{dc} only (railways)
- Challenging for high voltage

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Basic Principle of a DCCB

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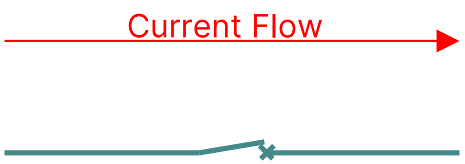
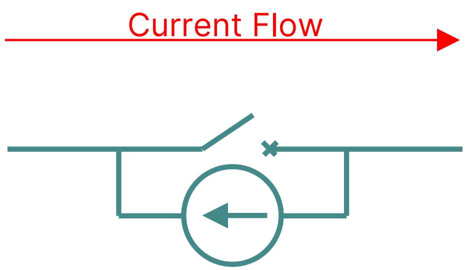
Before opening



- Very low resistance (ideally zero)

During opening

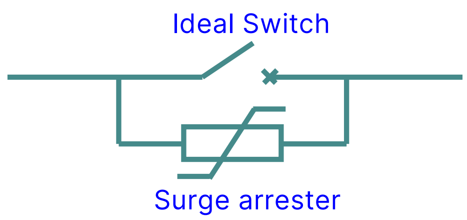


- Inserted voltage source opposing current

After opening

- Very high resistance (ideally ∞)

Simplified equivalent circuit



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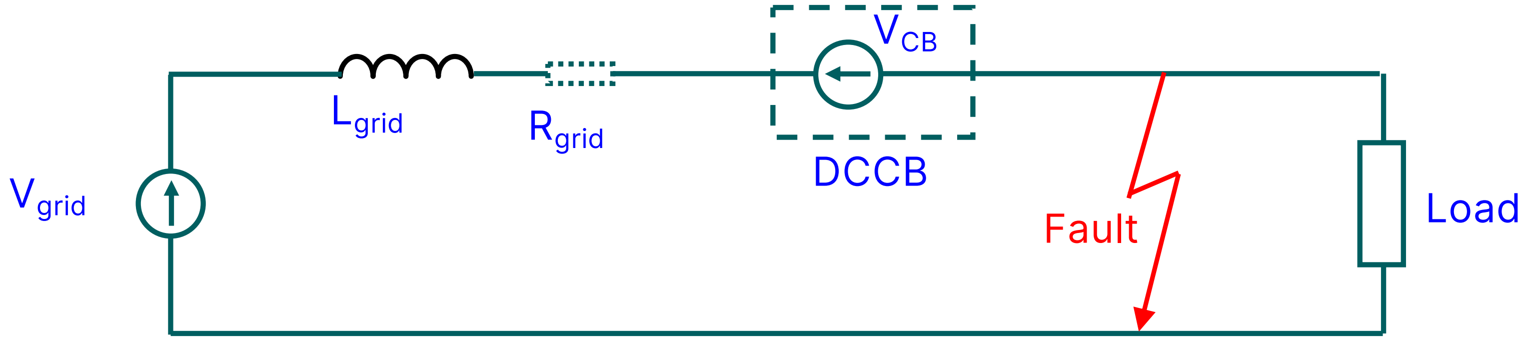
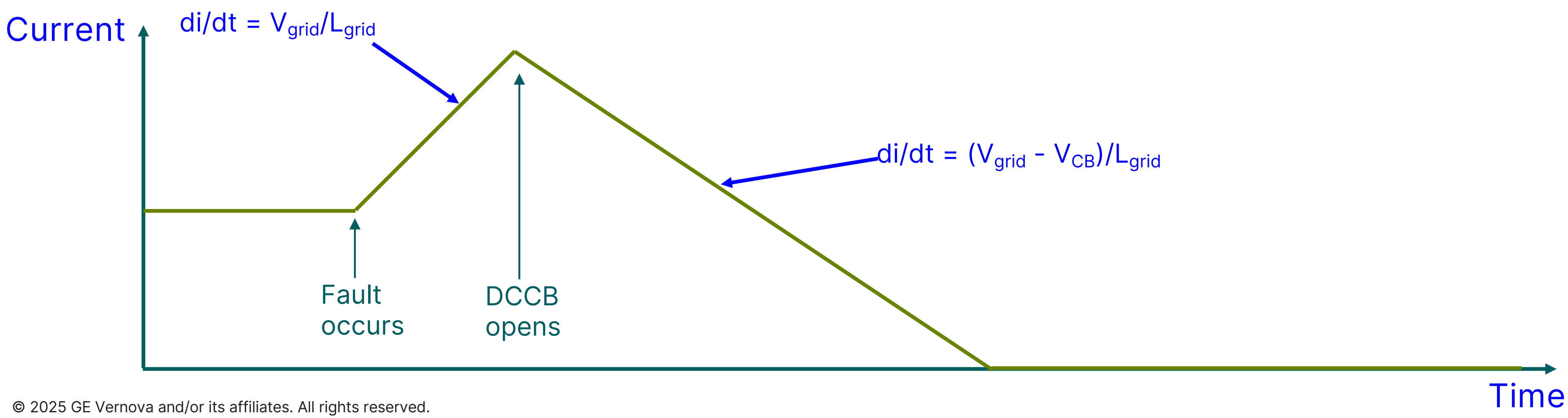
Fault clearing duty of DCCB





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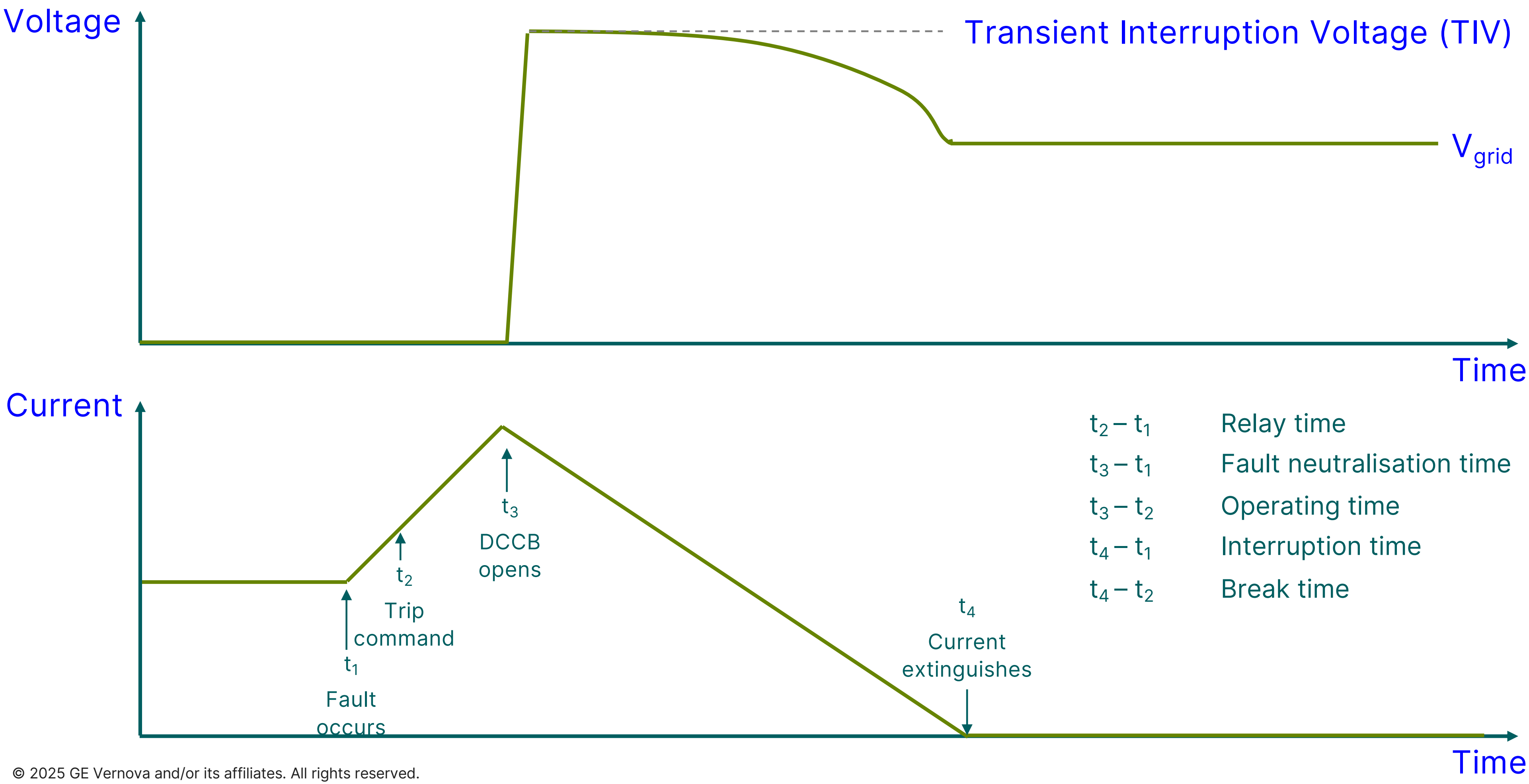
Fault clearing duty of DCCB



$t_2 - t_1$	Relay time
$t_3 - t_1$	Fault neutralisation time
$t_3 - t_2$	Operating time
$t_4 - t_1$	Interruption time
$t_4 - t_2$	Break time

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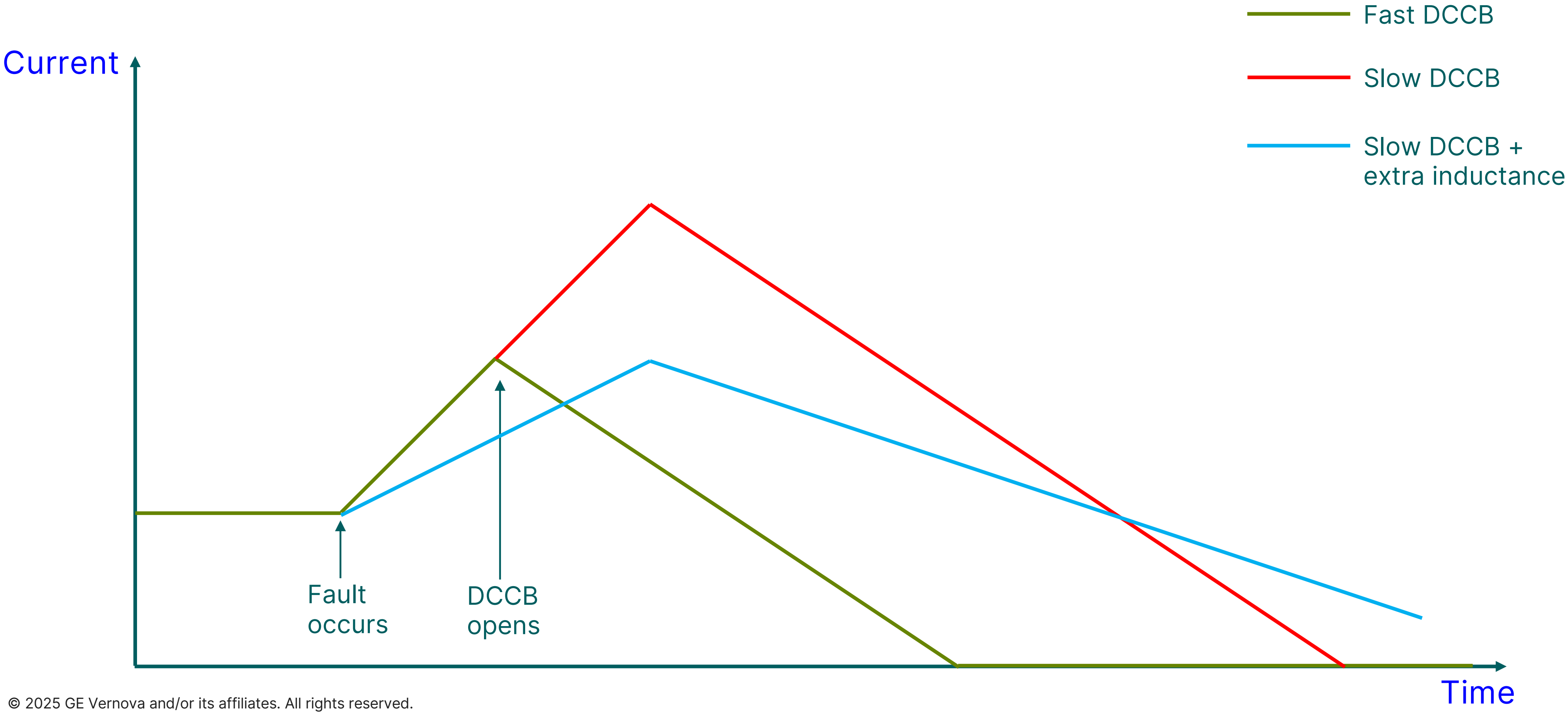
Why speed matters



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Why is interrupting DC difficult?

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- Why can't you just open the electrical contacts?
- https://www.youtube.com/watch?v=GMbN9nb3qyk
- And this is not even with DC…
- Note the shape. This is caused by the hot ionized gas rising.
- The shape led Sir Humphry Davy to coin the name "arc" (=arch) around 1803.

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Arc characteristics

- Electrical arc is a very complex, non-linear resistor
- "Arc voltage" depends on current, temperature, pressure, gap length and contact materials
- Arc voltage tends to **decrease** when current **increases** (negative resistance effect)
- But as a general "rule of thumb", arc voltages are typically of the order of **tens of volts**.
- This is orders of magnitude lower than we need for HVDC!

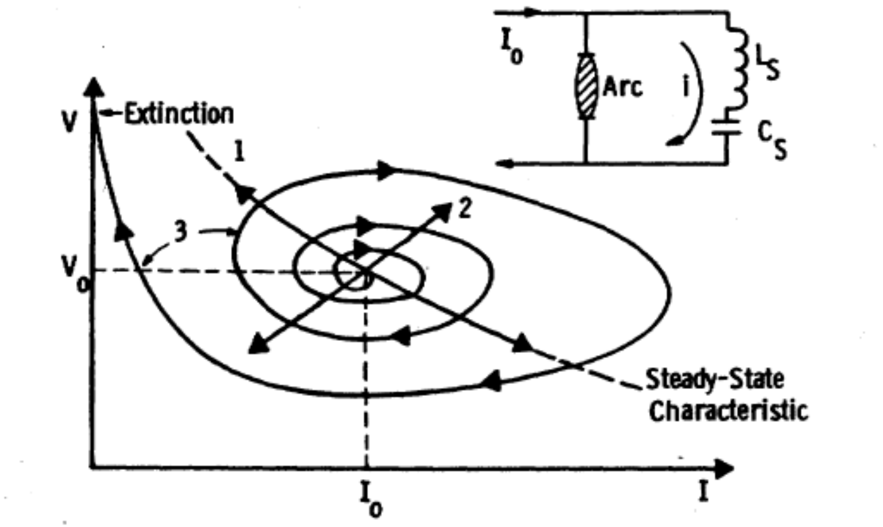

Fig. 5. Physical description of the arc-circuit instability. L_S is the stray inductance of the shunt circuit.

A. Lee et al, "The Development of a HVDC SF6 breaker", IEEE transactions on Power Apparatus and Systems, PAS-104, No. 10, 1985.

This article describes the world's first ever HVDC circuit-breaker, at the Celilo terminal of Pacific Intertie in USA.

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Low-voltage DCCB for railway applications

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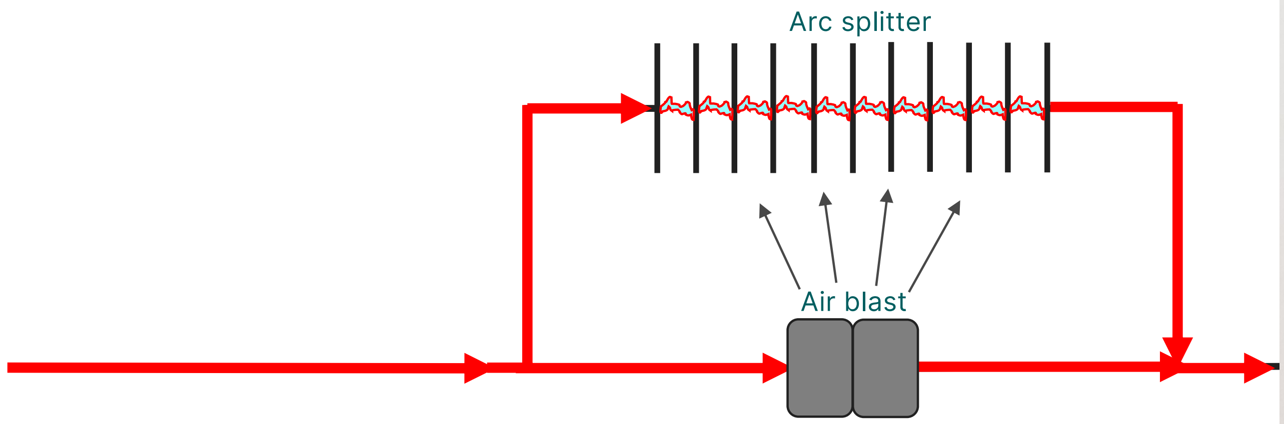

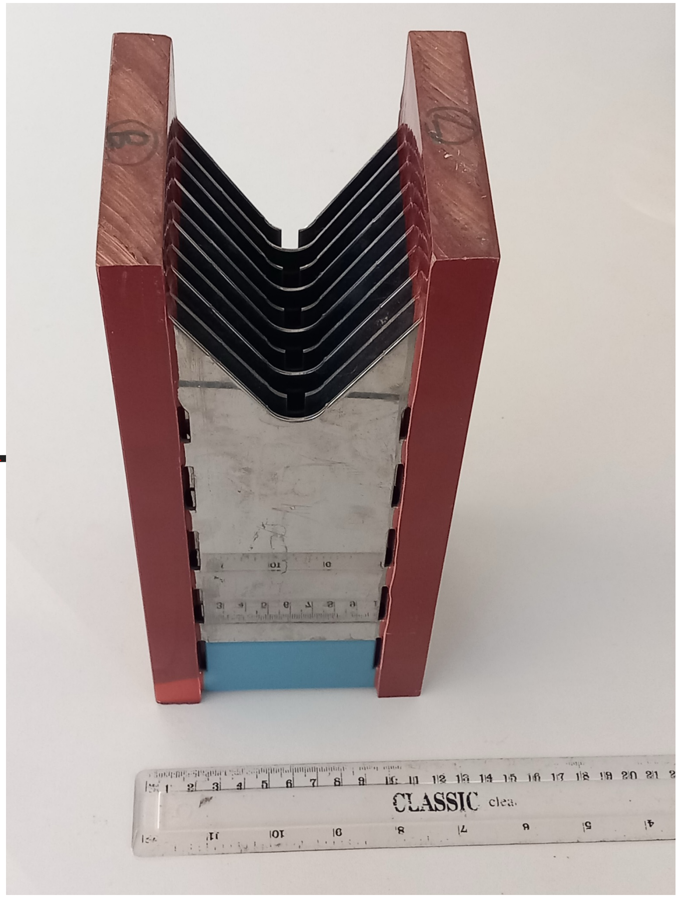

Arc splitter from LV railway DCCB

1. Contacts closed

2. Contacts separate. Arc established between contacts.

3. Arc transfers to arc splitter. Arc voltage multiplied by number of splitter gaps.

4. Current extinguishes

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Three main types of DCCB for HVDC

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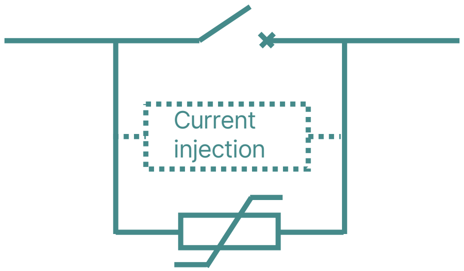
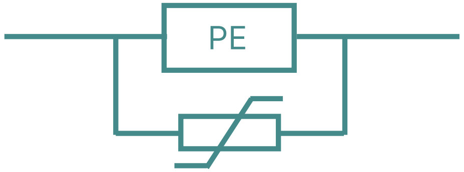
Mechanical



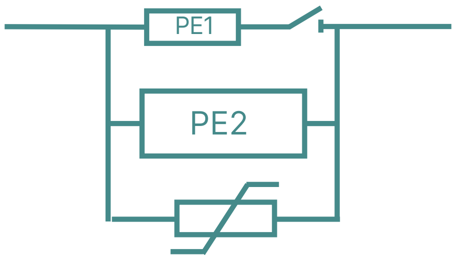
- ✓ Relatively cheap
- ✓ Negligible losses
- ? Speed and interruption capability vary greatly between sub-types
- × Interrupter opens with arcing (➔ wear and tear)

Solid-state (Power Electronic)



- ✓ Super fast (microseconds)
- ✓ Excellent controllability
- ✓ No moving parts
- × Expensive
- × Extremely high power losses

Hybrid



- ✓ Fast (few milliseconds)
- ✓ Good controllability
- ✓ Low losses
- ? UFD has moving parts, but opens without arcing
- × Relatively expensive
- × Complex

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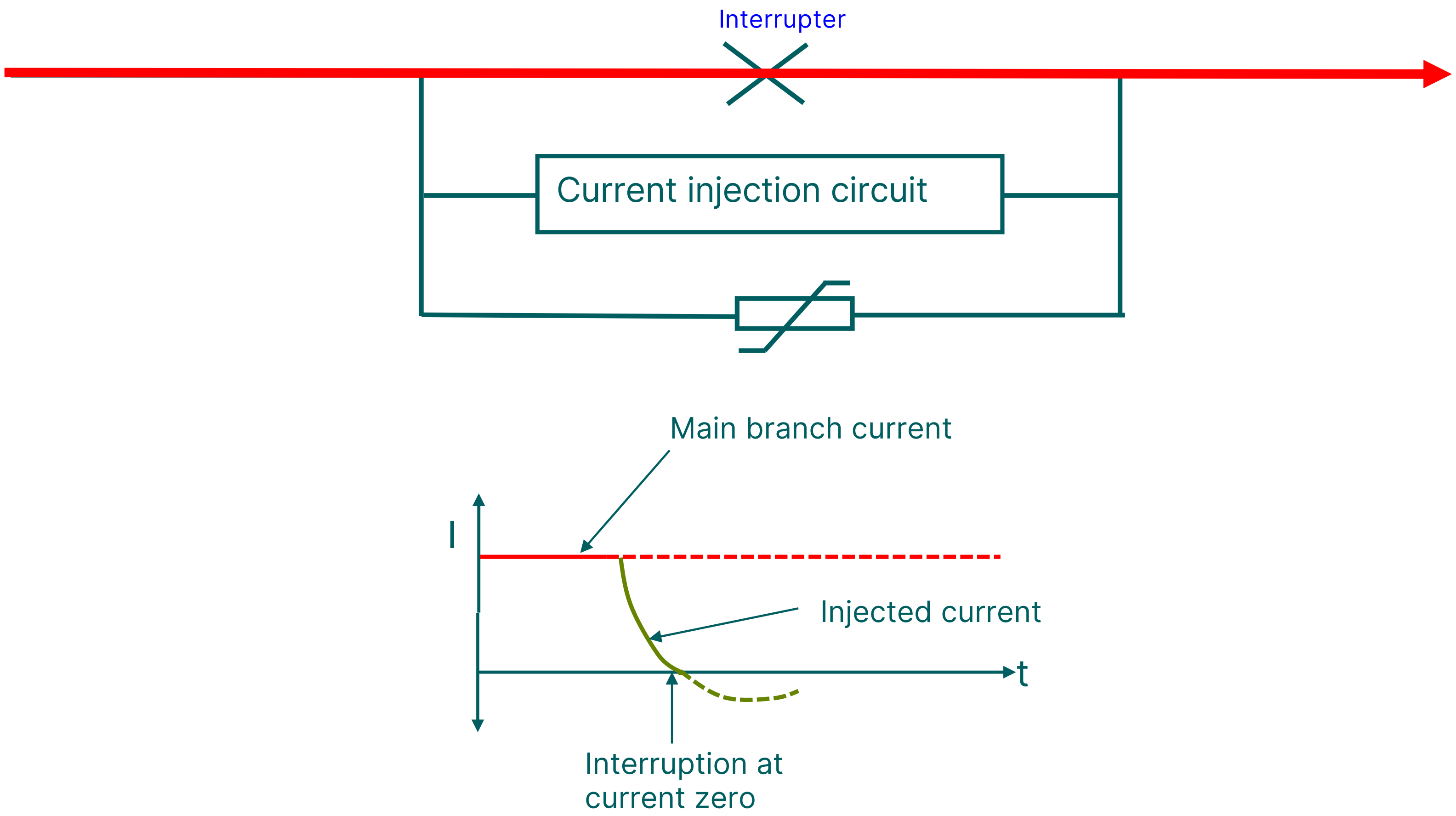
Mechanical DCCB with current injection circuit



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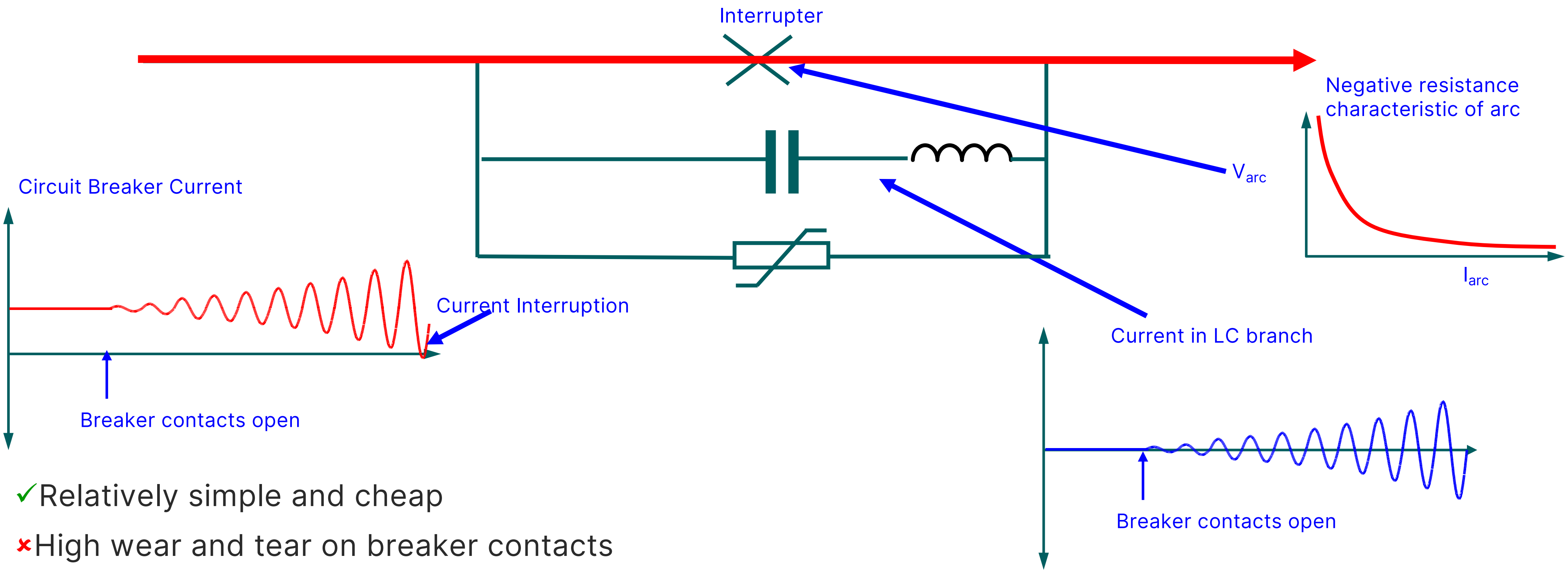
Mechanical - Passive Resonant DCCB



- ✓ Relatively simple and cheap
- × High wear and tear on breaker contacts
- × Much too slow for DC grid applications

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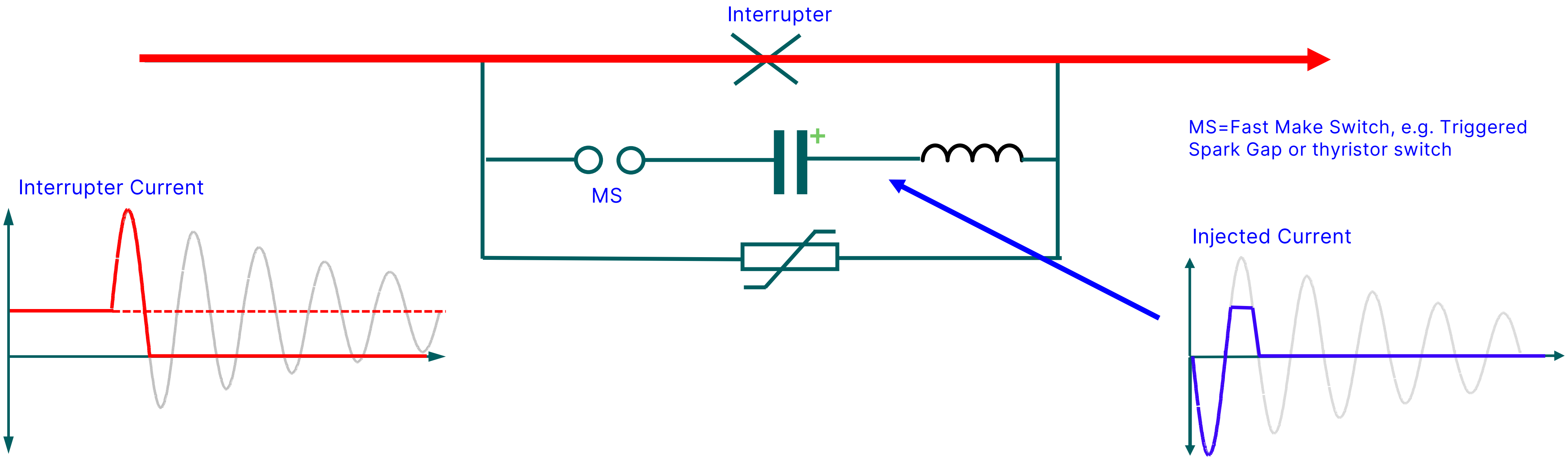
Mechanical – Active Current Injection DCCB

(a): Pre-charged capacitor and Make Switch



- ✓ Relatively simple and cheap
- × High wear and tear on breaker contacts
- × Relatively slow
- × Poor performance at low current

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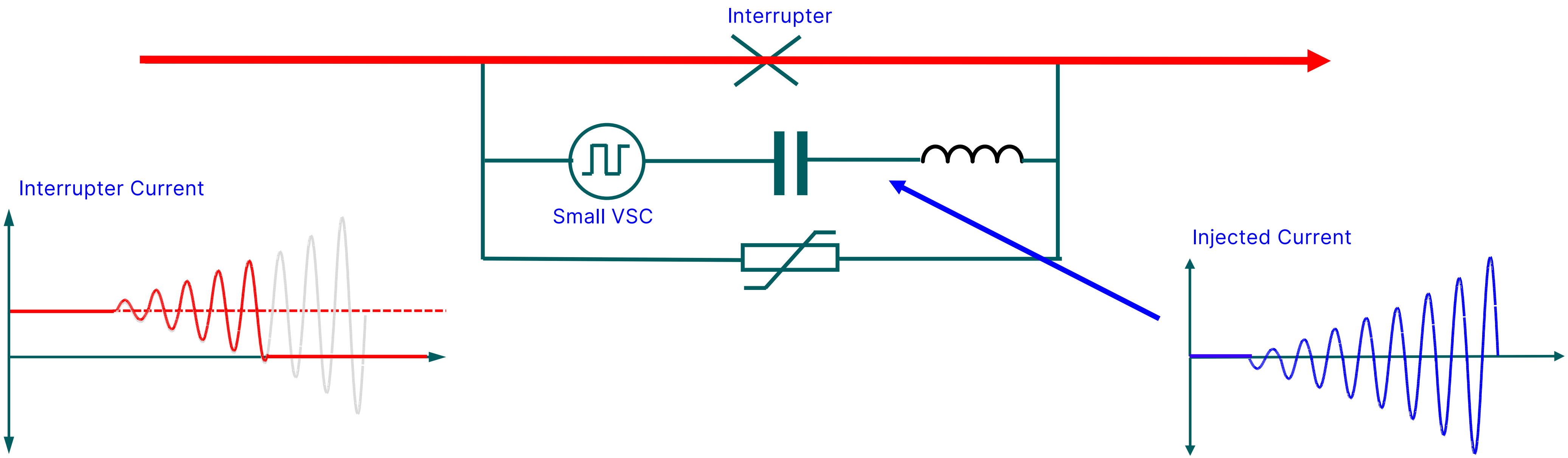
Mechanical – Active Current Injection DCCB

(b): VSC-Assisted Resonant Commutation



- ✓ Relatively simple and cheap
- × High wear and tear on breaker contacts
- × More complex

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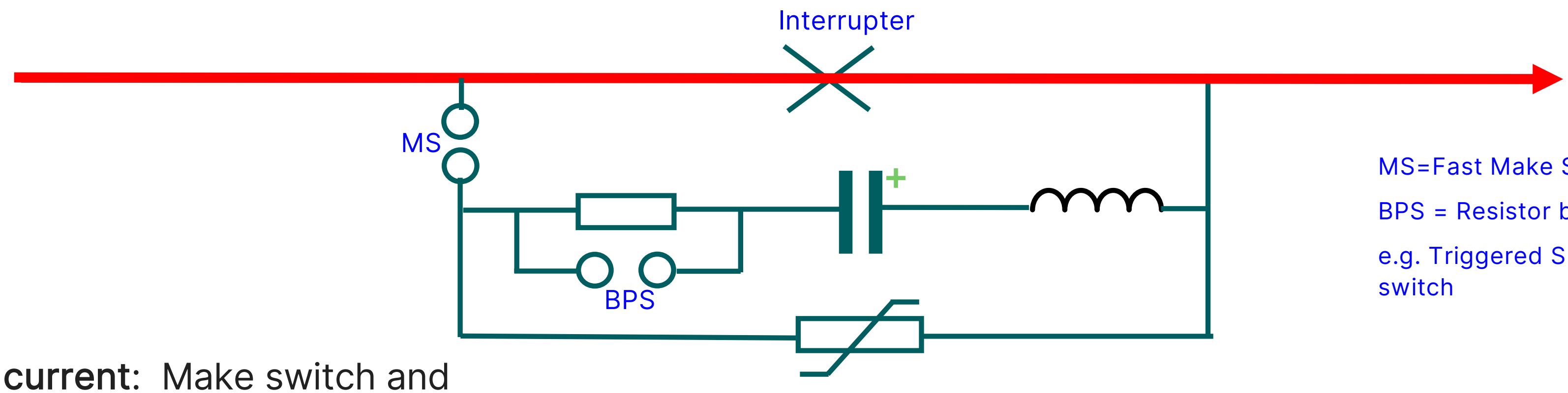
Mechanical – Active Current Injection DCCB

(c): Adjustable current injection

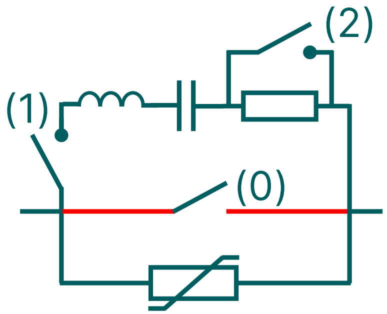


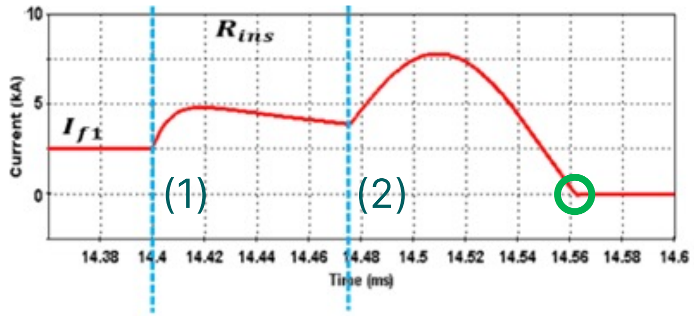
MS=Fast Make Switch

BPS = Resistor bypass switch

e.g. Triggered Spark Gap or thyristor switch

- **High current:** Make switch and bypass switch closed at same time
- **Low current:**
- Make switch closes first
- Capacitor voltage decreases (overdamped response)
- Then bypass switch closes





From paper at IEEE-GM, Denver, 2022.

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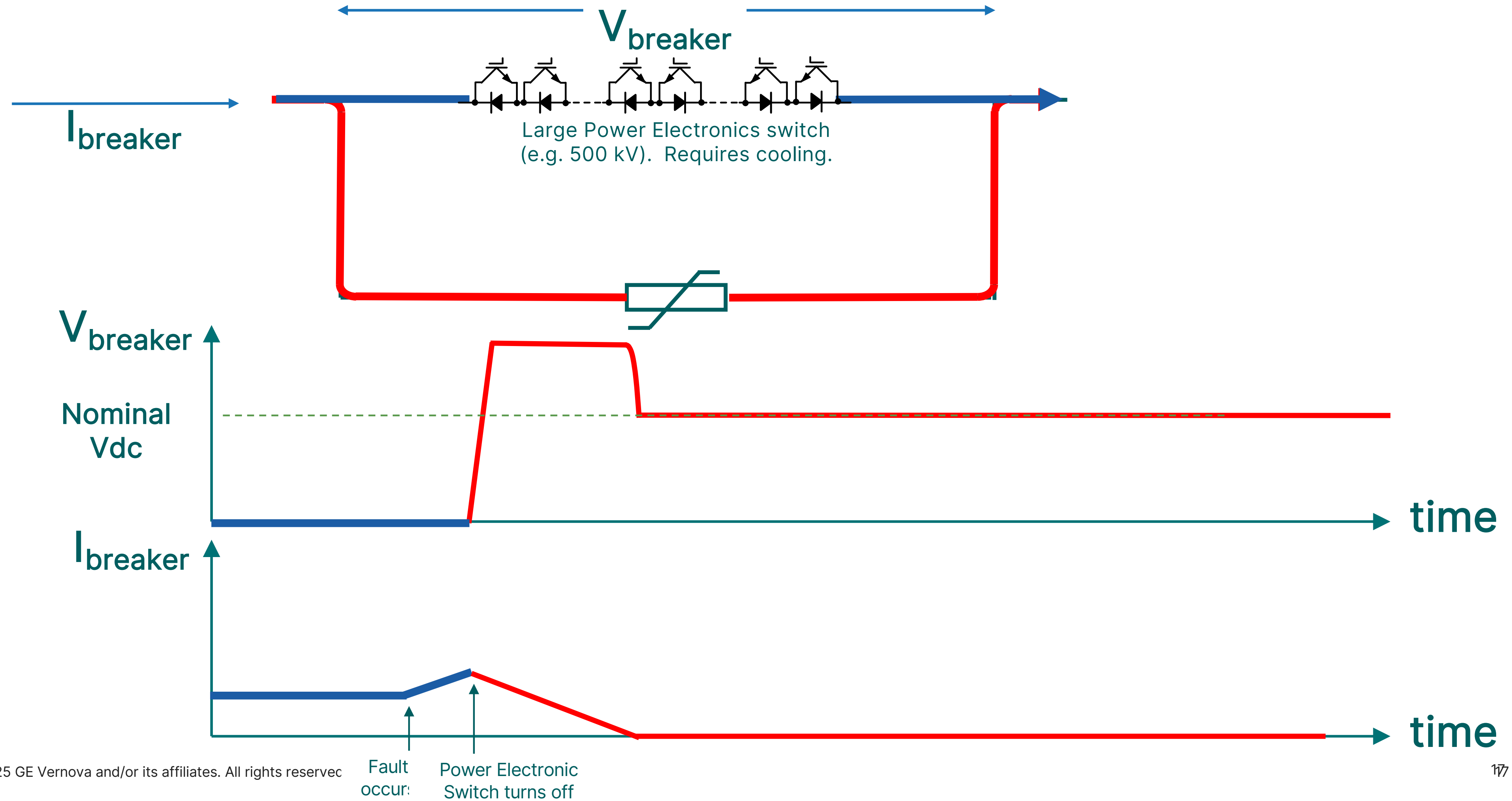
Solid-state (power electronic) DC circuit-breaker



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Hybrid DC circuit-breaker: operating principle

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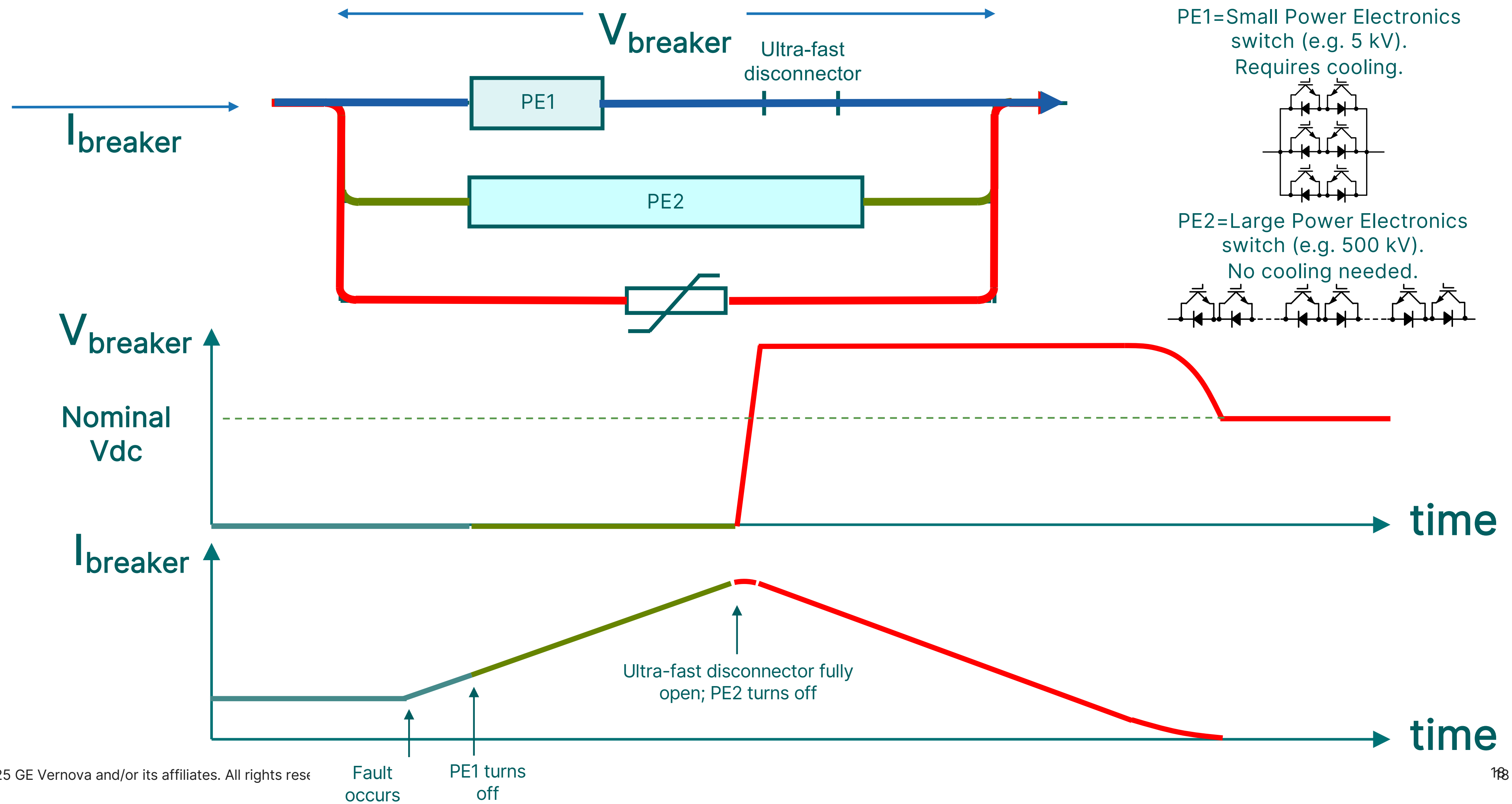

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Where do we go from here?

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- Several manufacturers built and tested DCCB prototypes as long ago as 2013
- In China, a few full-scale multi-terminal HVDC systems are using DCCBs
- But outside China, progress has been very slow (lack of market demand)
- ...until recently.
- Now several European TSOs are planning (limited) multi-terminal HVDC systems
- DCCBs will become essential in these systems, to avoid loss-of-infeed limits
- First installations expected to be in service around 2030.
- Still plenty of scope for innovation and R&D!

References/further reading:

- CIGRE TB683: Technical requirements and specifications of state of the art HVDC switching equipment
- CIGRE TB873: Design, test and application of HVDC circuit-breakers
- “Performance requirements for DC circuit breakers for multi-terminal HVDC systems”, C.C.Davidson, CIGRE B4 Colloquium, Vienna, Sept. 2023.

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