Fault current interruption in HVDC networks

Tim Schultz

Structure

1. Power transmission basics
2. Current developments

3. Research:
   Fault current interruption in HVDC grids

   - Simulation:
     How are breaker components stressed by faults?

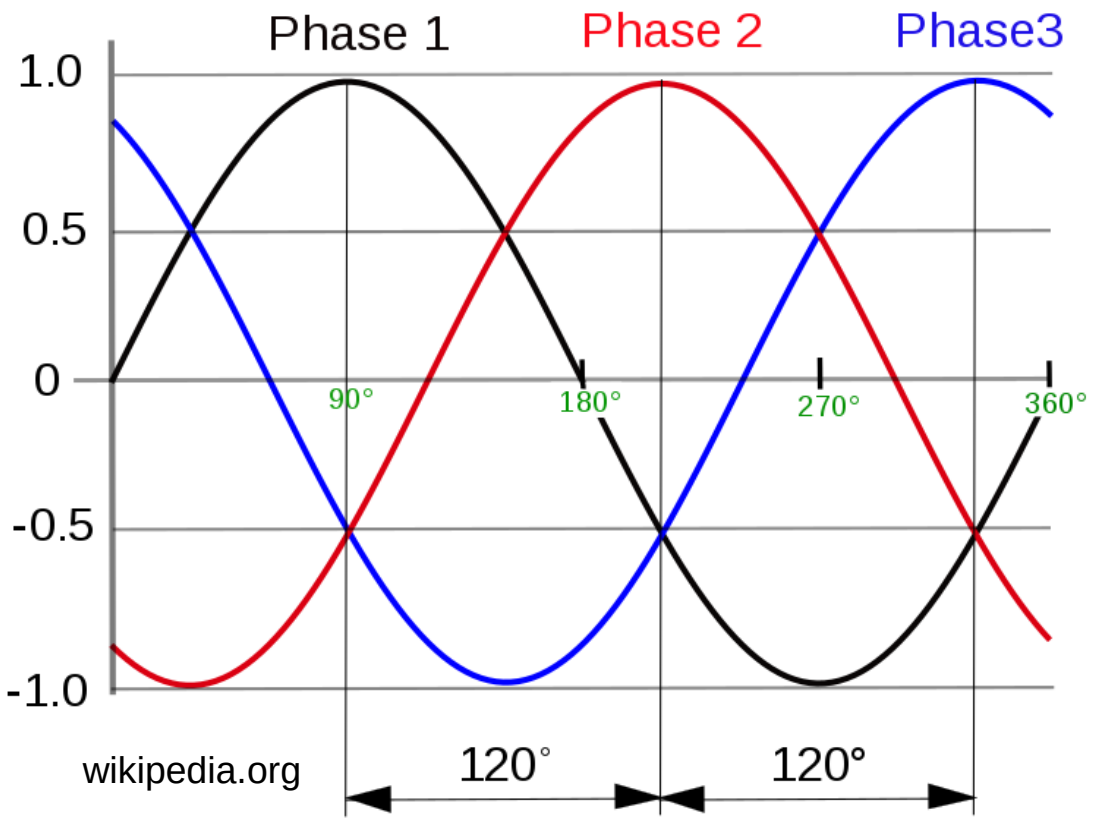
   - Experiments:
     Investigating and improving limit performance of mechanical interrupters

Attention getter

- In a couple of years, the lights in your living room will be powered by offshore wind farms in the north sea.

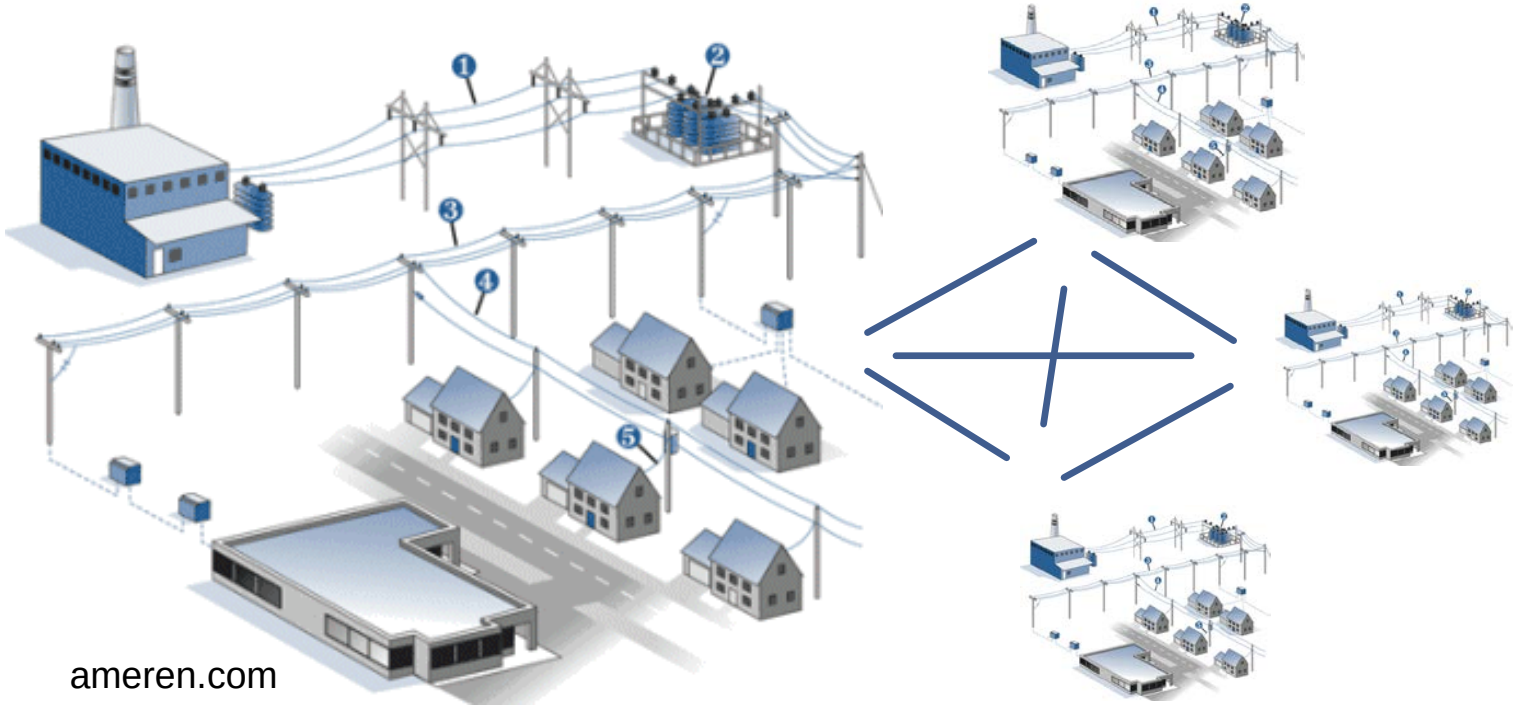
- You will not recognize the tree that fell into the transmission line somewhere near Frankfurt, because HVDC circuit breakers will have rerouted your power flow in much less than the blink of an eye.

Power transmission 101: Alternating Current (AC)



Traditionally, energy transmission and distribution systems have been (almost) exclusively realized with AC technology.

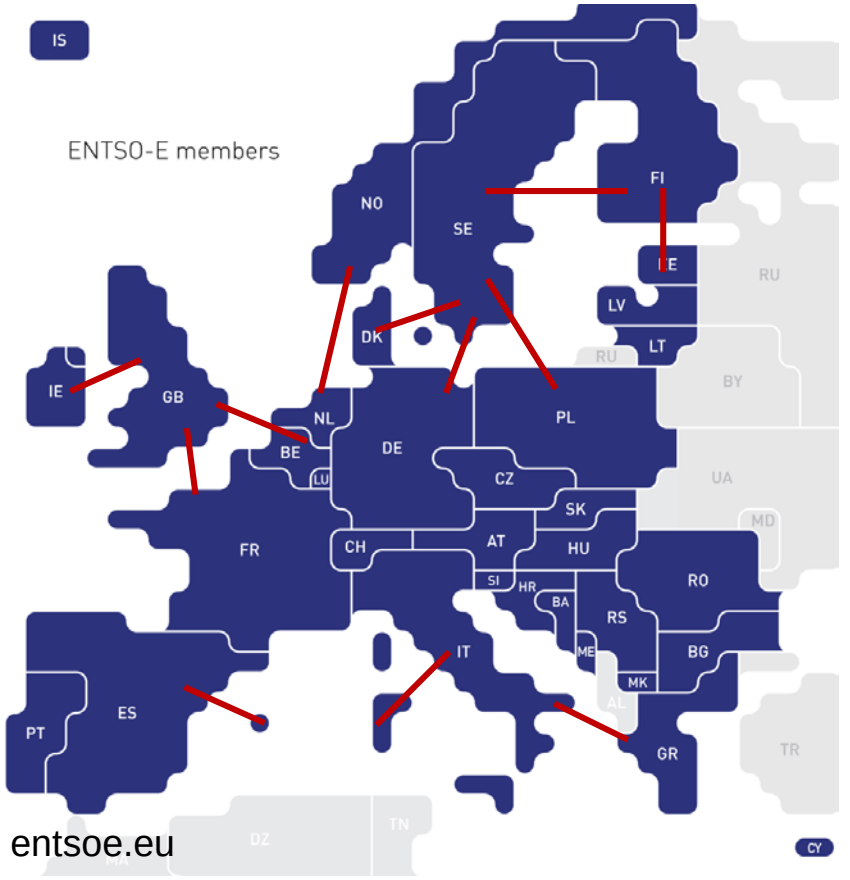
wikipedia.org



ameren.com

Generation	Transmission	Distribution
30kV	420kV	20kV / 0.4kV

10 years ago: Continental size HVAC grids with high reliability (interconnected by a few HVDC links)

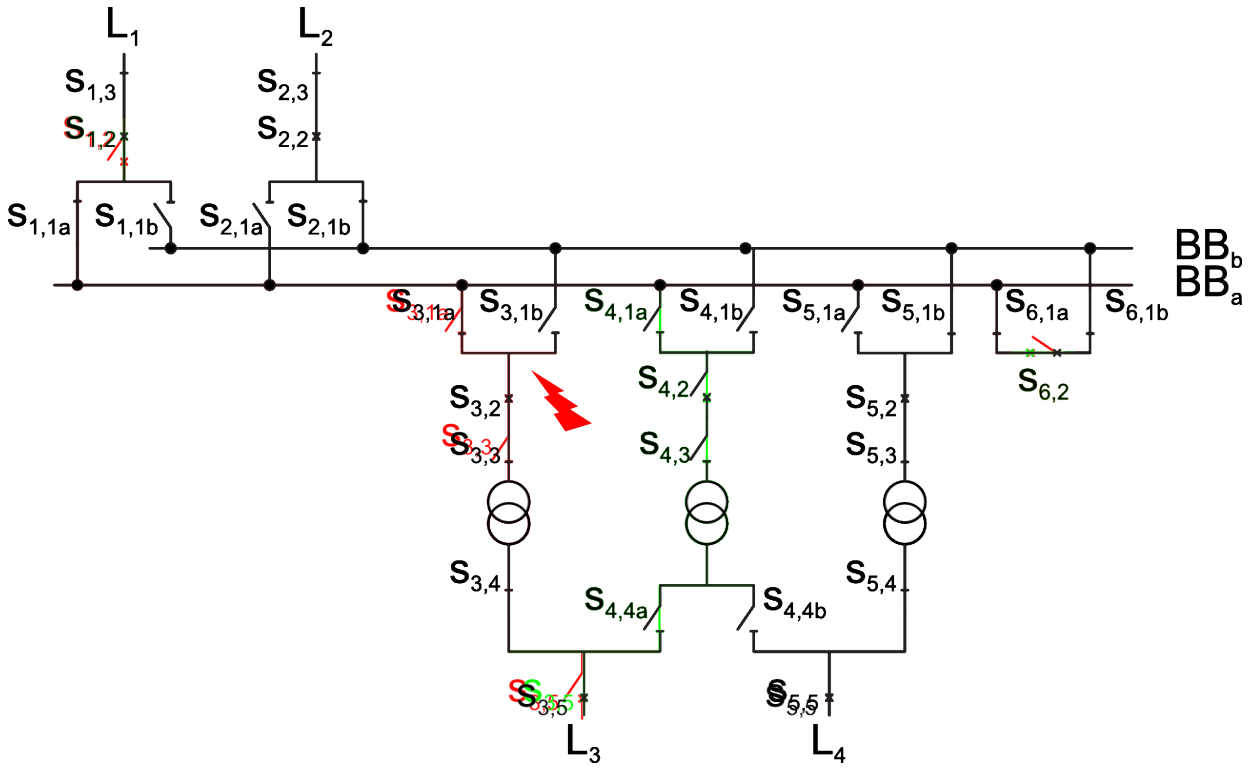


entsoe.eu

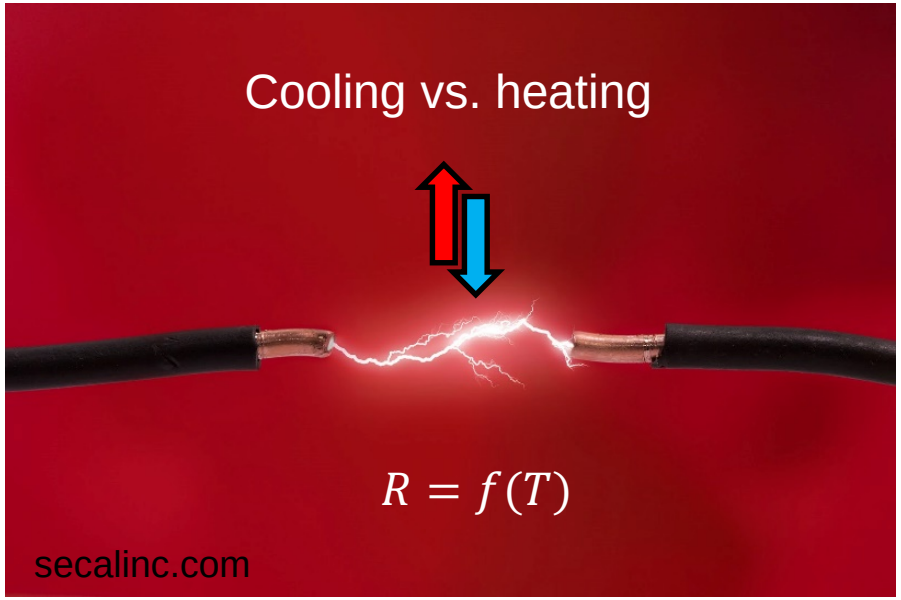
Switches make the system flexible and reliable. In case of a fault, the short circuit current is interrupted by circuit breakers.

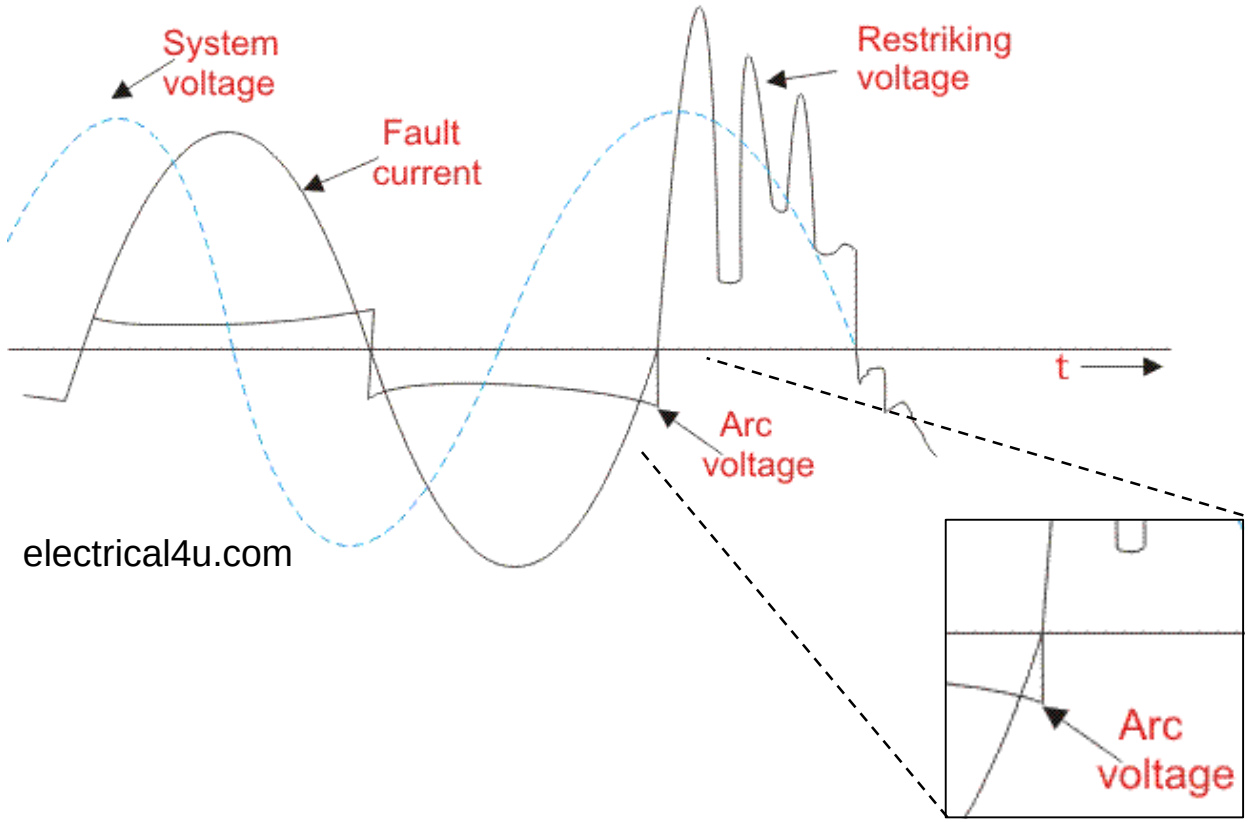
Disconnector
- «no load» switching

Circuit breaker
- fault current interruption

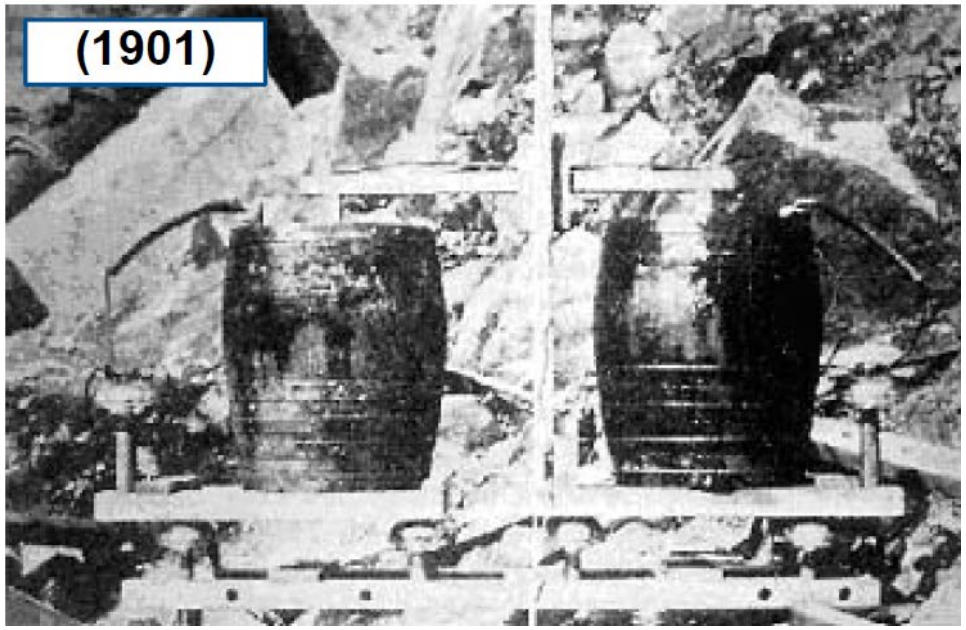


In HVAC, currents are interrupted by separating mechanical contacts. Actual interruption happens at current zero.





After decades of research and progress, gas blast circuit breakers are state of the art in HVAC.



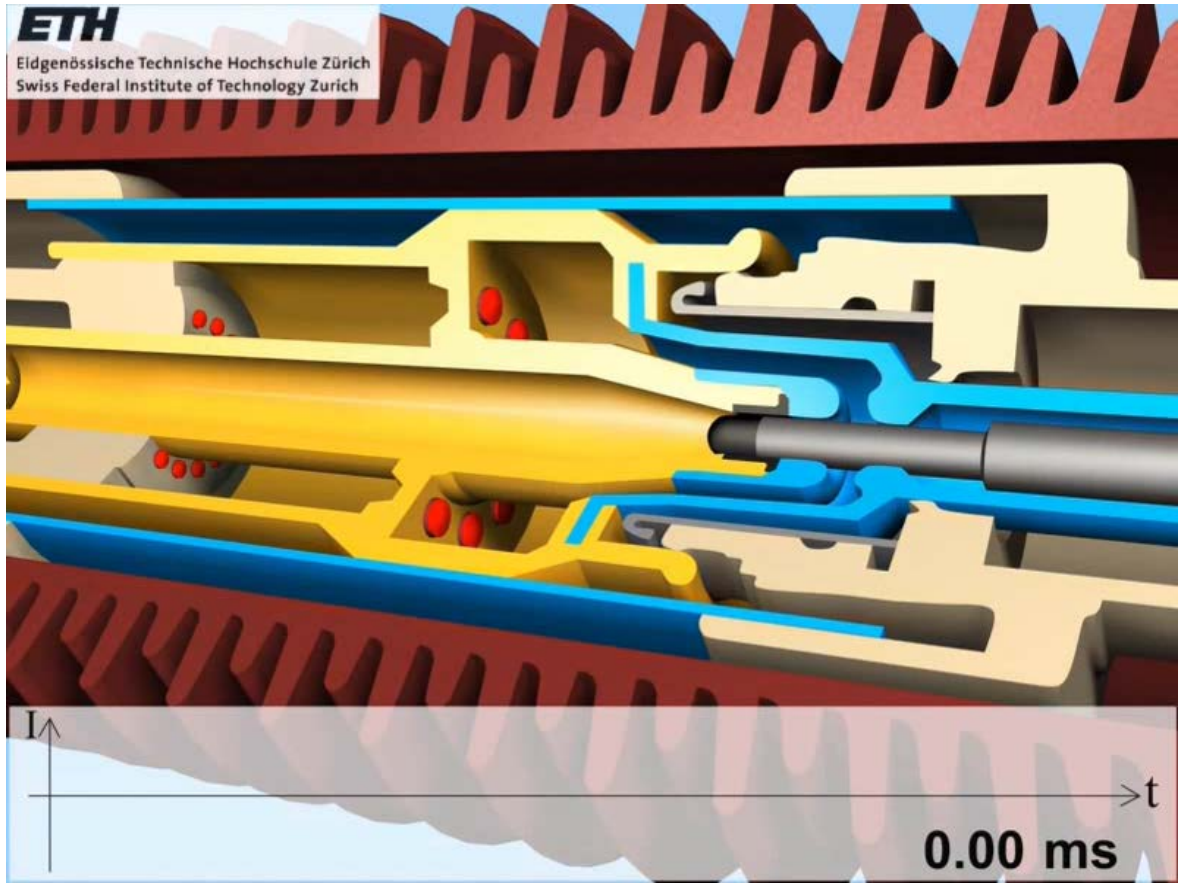
Garcon

40kV, 200A
service life: 1 year (ending in explosion)

nhvsgroup.com

1200kV, 80 000A
service life: decades

Complexity of modern switchgear:
Current interruption of «self-blast circuit breaker»

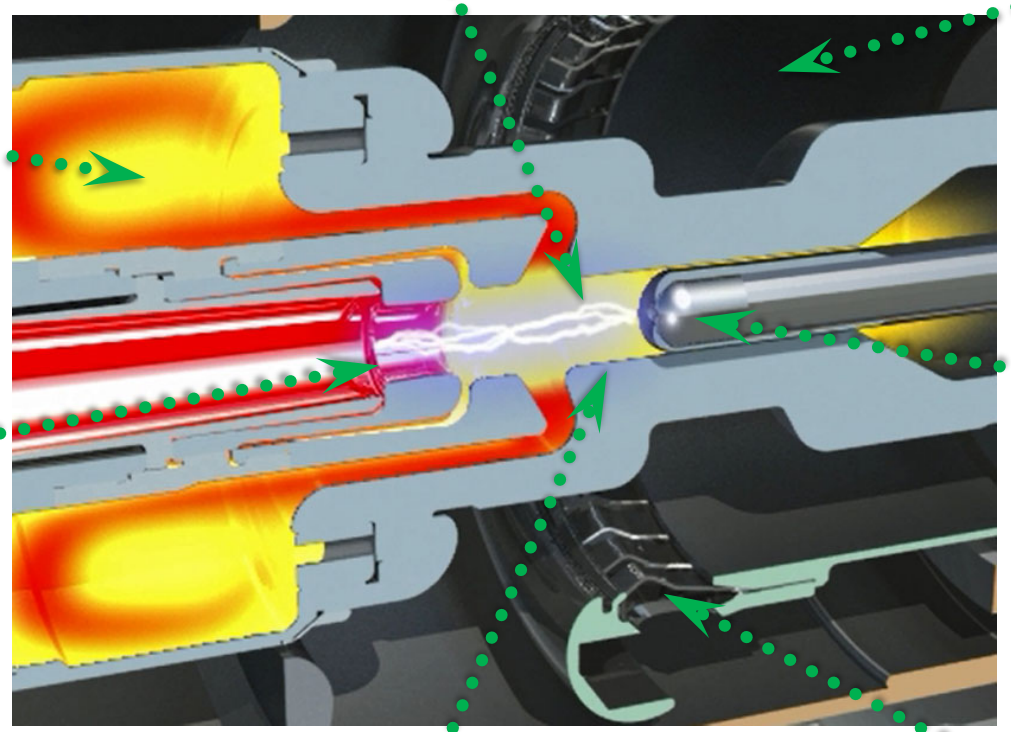


Designing a mechanical interrupter is a highly interdisciplinary challenge.

Arc plasma
(@ 20k K, 80/250kA)

double motion contacts
(a = x00 g)

gas flow
(super-sonic)



Arcing contacts
(tungsten-copper, arc «resistant»)

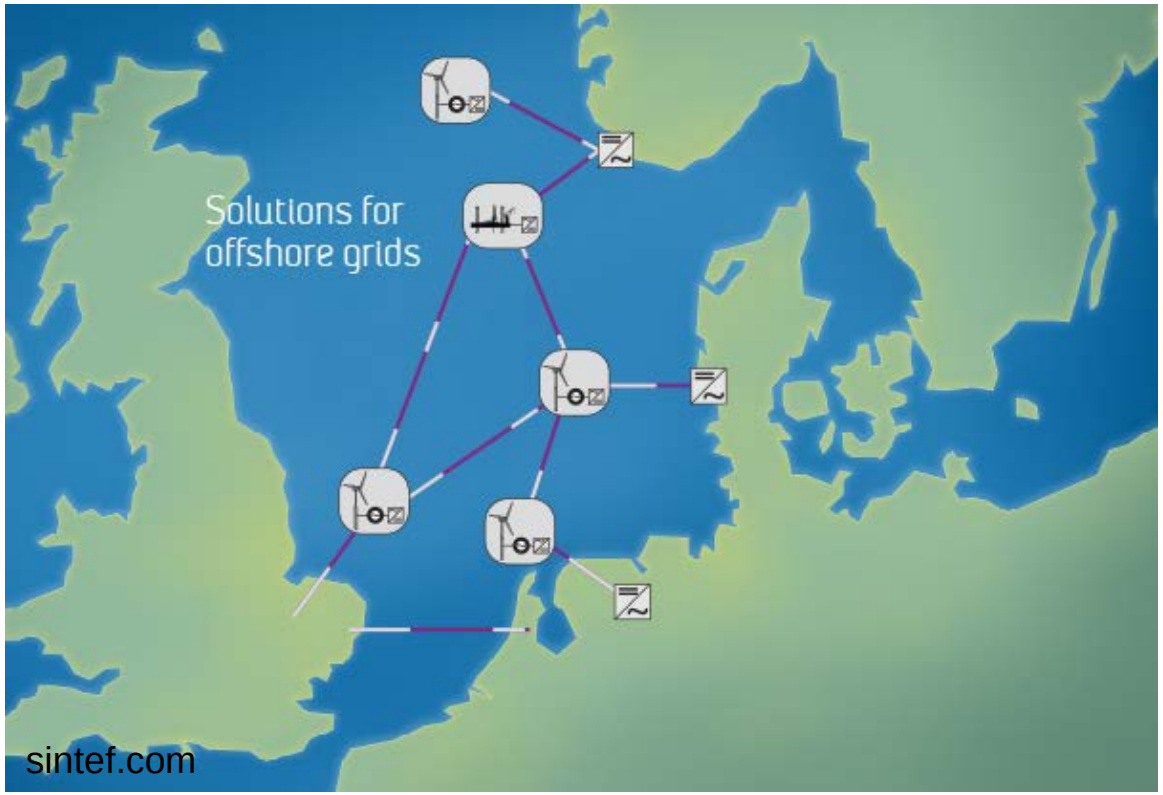
insulation
(gas, SF6, GWP 23 000)

think-grid.org

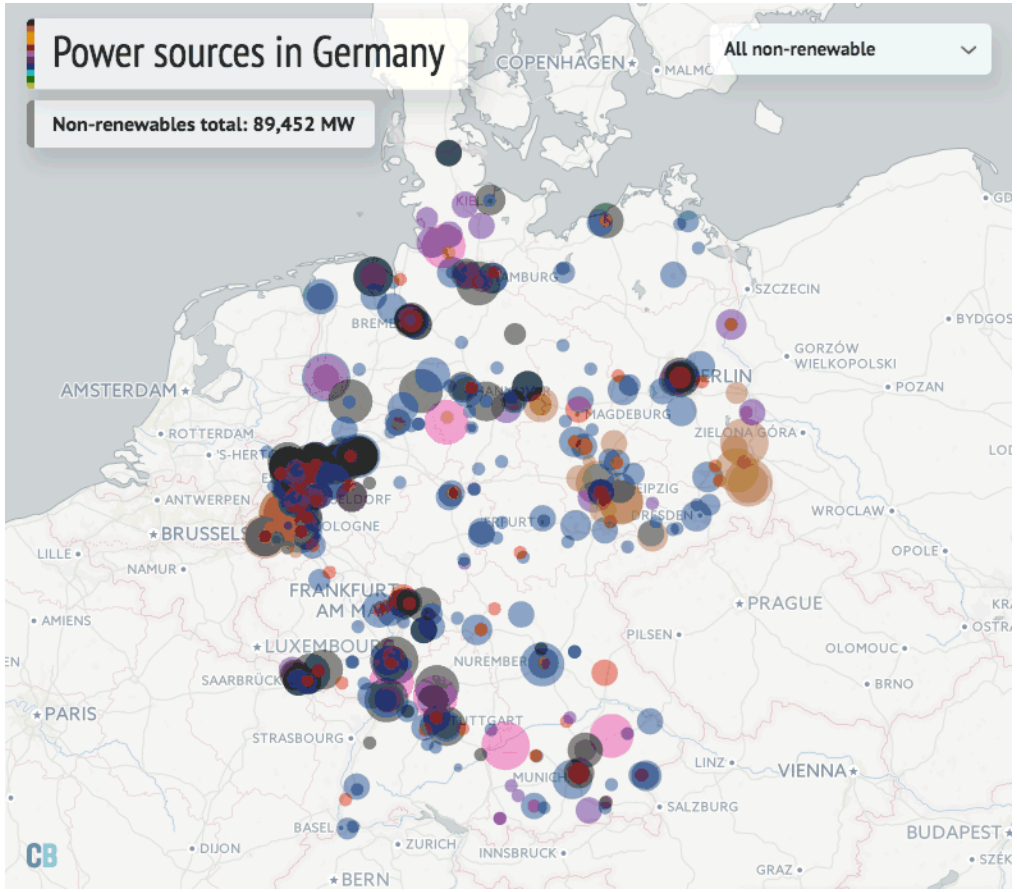
chemical reactions
(ablation, decomposition)

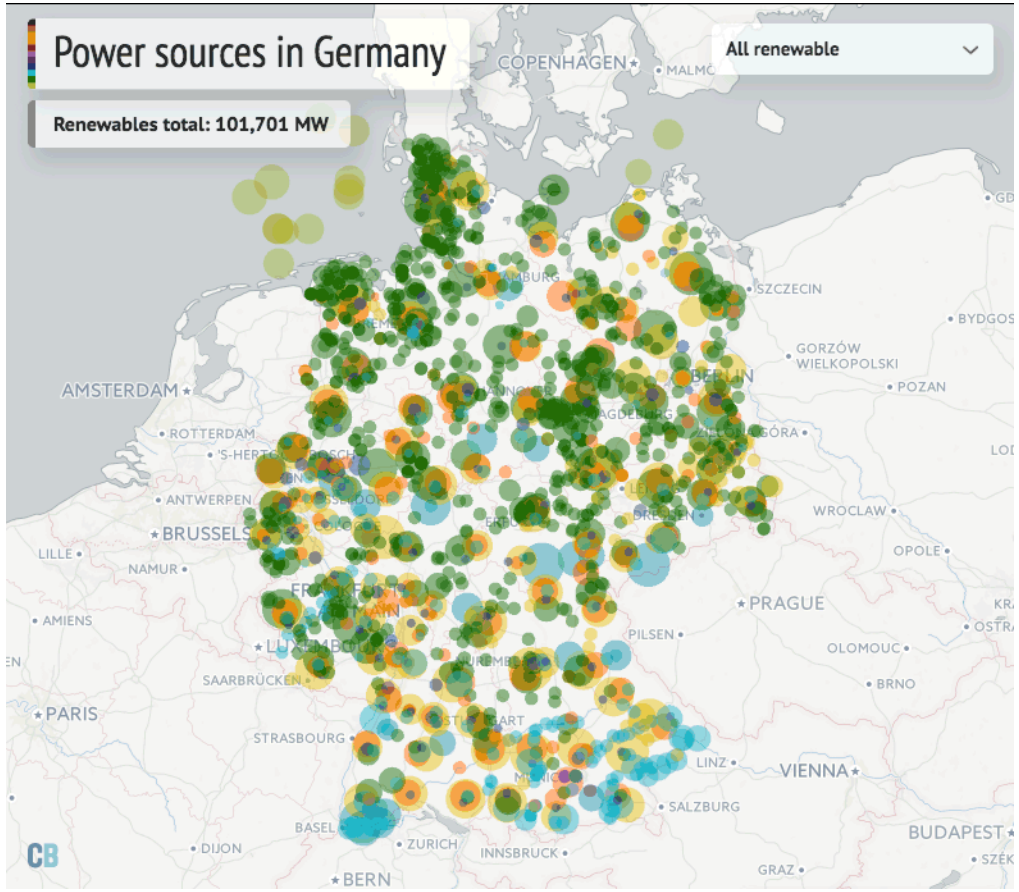
main contacts
(silver coated, highly conductive)

Power transmission 201: Recent developments



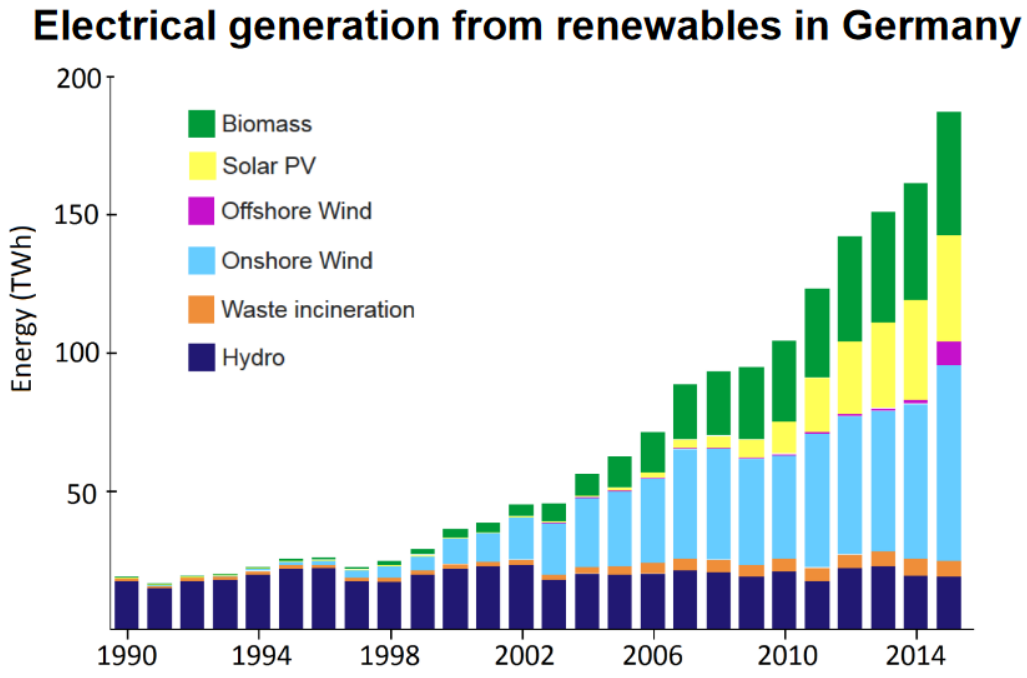
Decentralized renewable sources generate fluctuating power in sparsely populated areas.



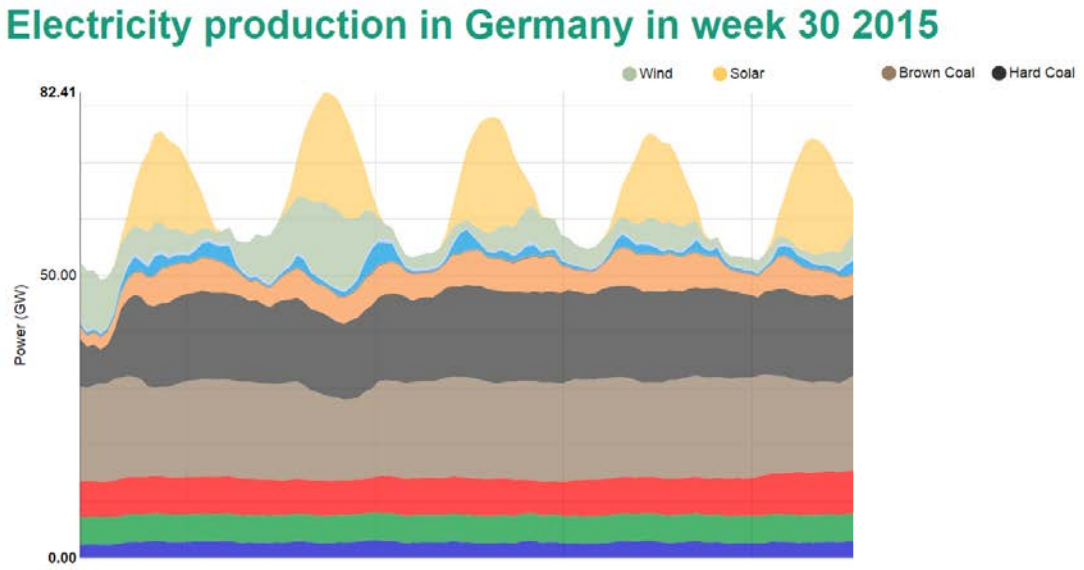


carbonbrief.org

A transition to renewable energy sources requires major changes in the transmission and distribution system.

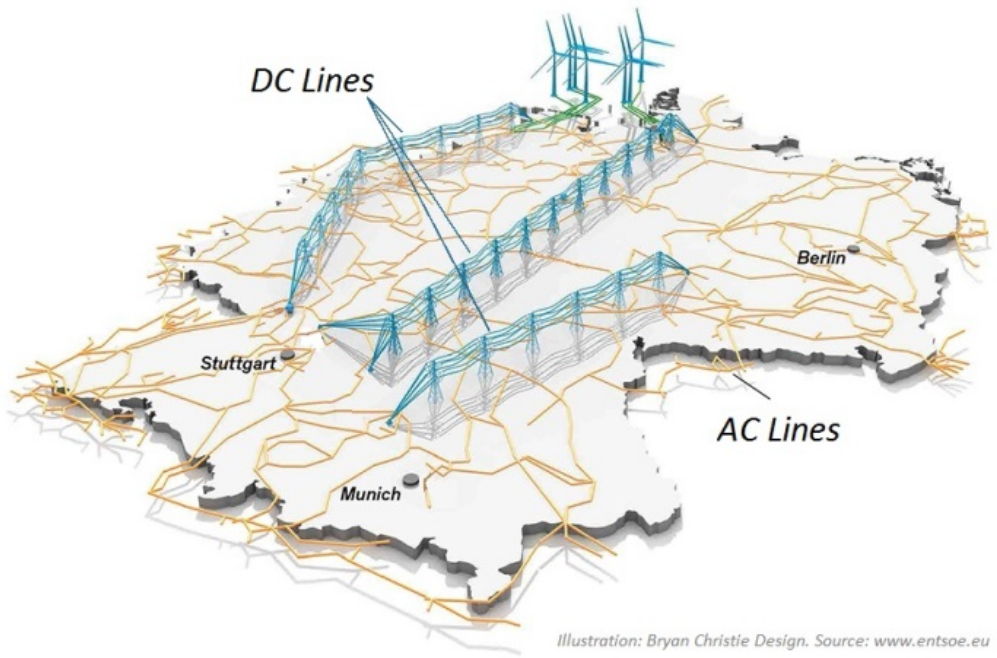


eneuerbare-energien.de



energytransition.org

HVDC links have to be extremely reliable as they become important for the stability of the connected HVAC grid.



entsoe.eu

Switzerland for comparison

economist.com

Currently, remote renewable energy sources are made accessible by point to point (P2P) HVDC links.

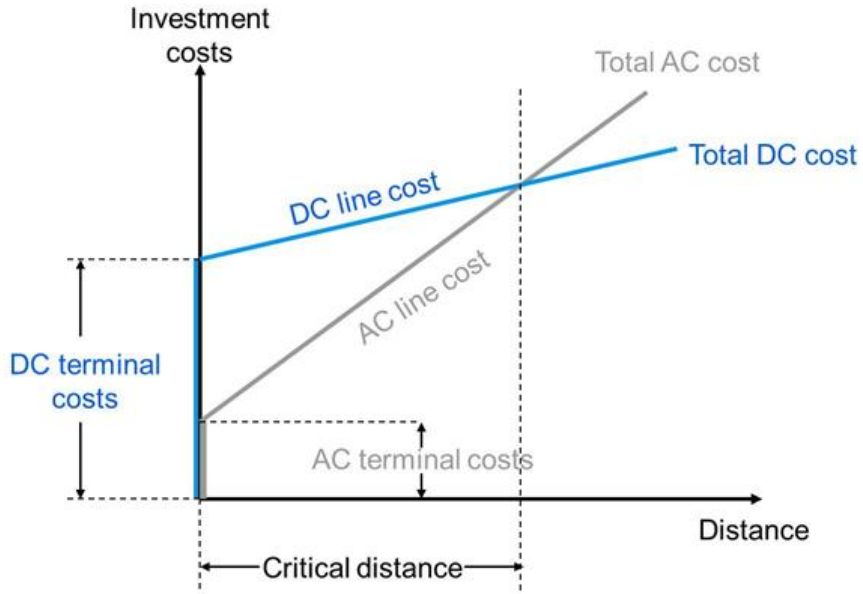
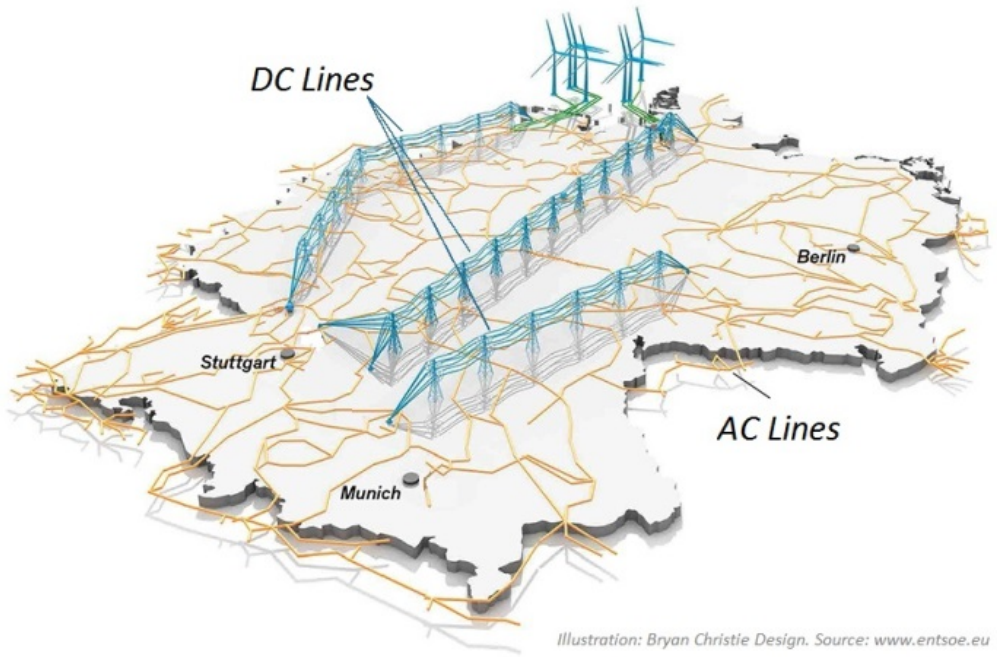


abb.ch

Line length	> 2 200 km (planned > 3 400 km) $(length\ border\ CH = 1852km)$
Line voltage	> ± 1 000 kV
Transmitted power	> 8 000 MW $(\hat{P}_{CH}(2017) < 10\,000\ MW)$

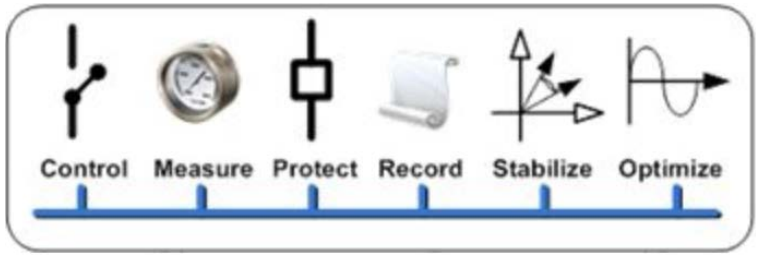
Grids can be higly reliable compared to links, but they are challenging to operate.



entsoe.eu

betterworldsolutions.eu

The requirements for a MTDC grid are similar to HVAC, but the technology is much more complex.



EnerNex

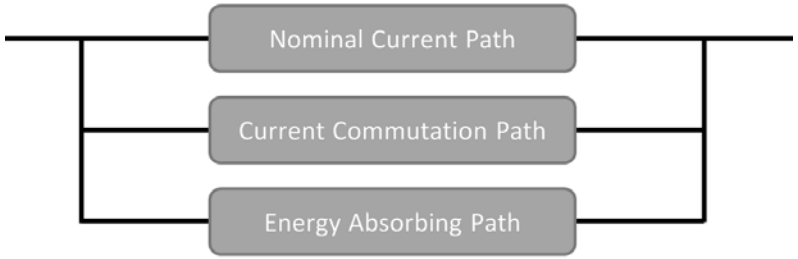
nationalgrid

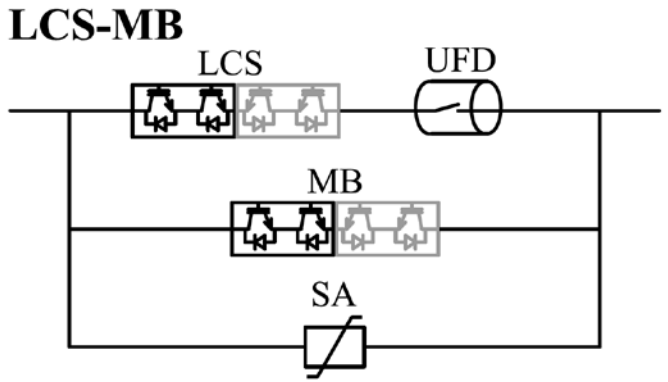
Standardization?

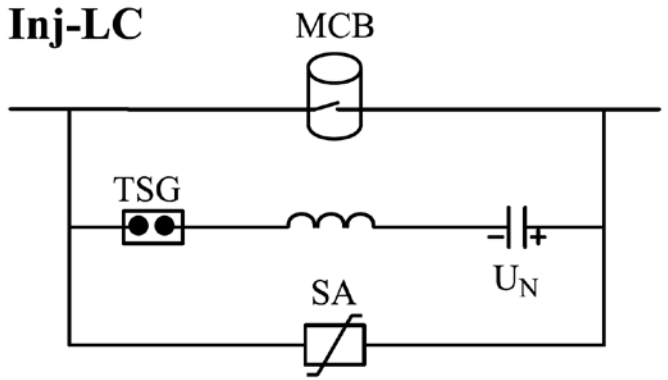
LinkedIn

To bringt a fault current to zero, a counter voltage has to be generated.

Typical structure of HVDC CB

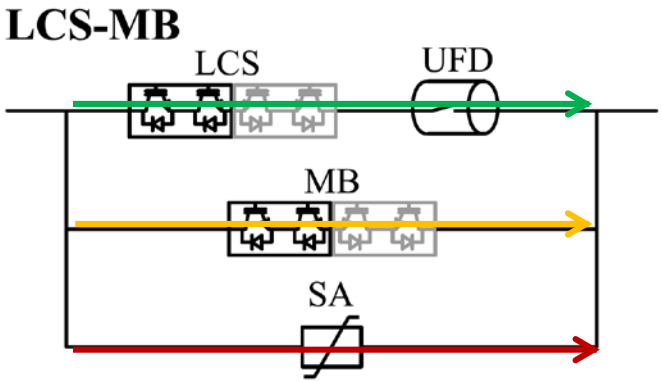


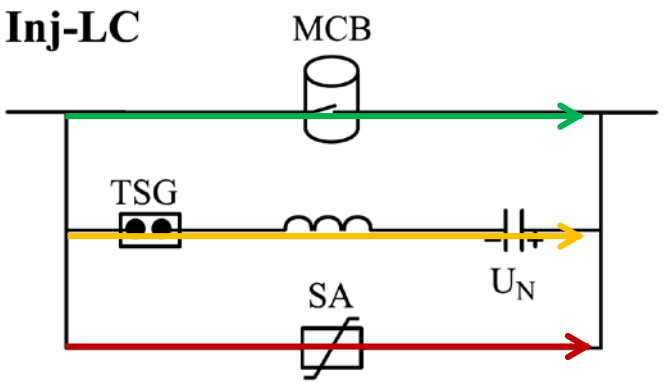


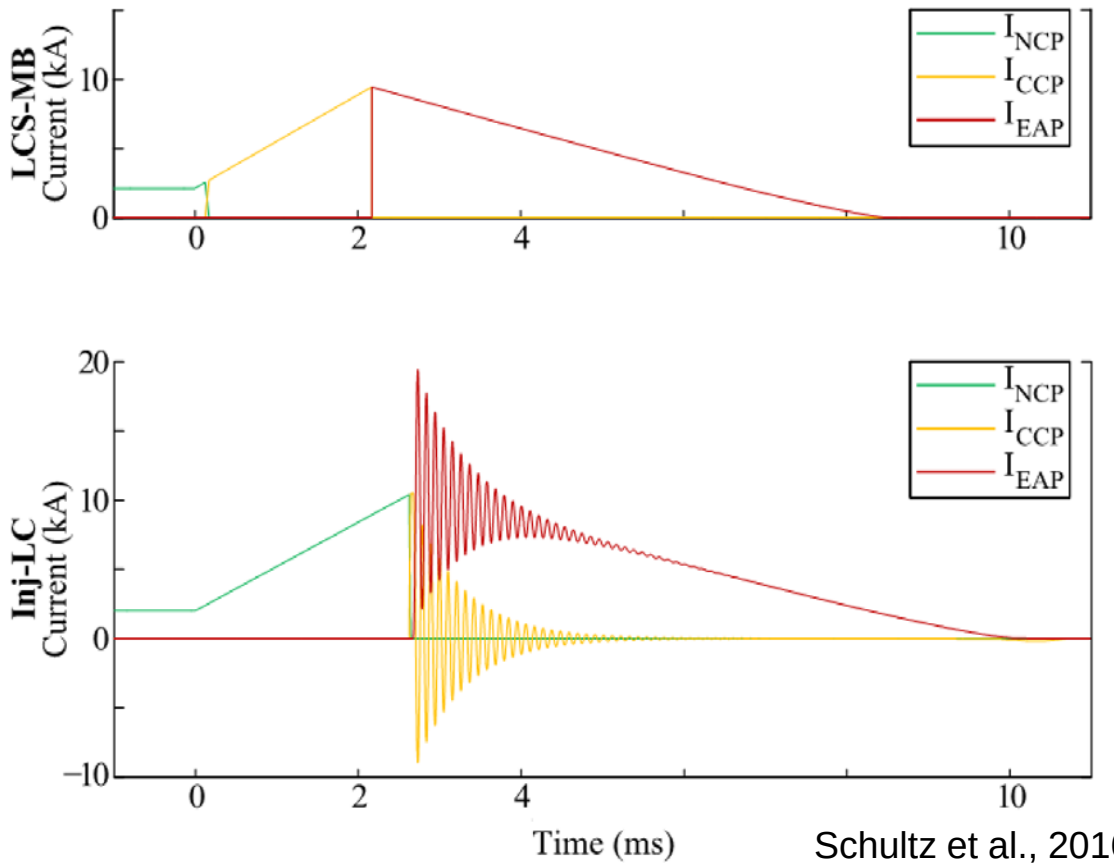


Trade-offs:

- Power electronic switches: **fast** but **expensive / higher losses**
- Mechanical switches: **low losses / cheap** but **slow**



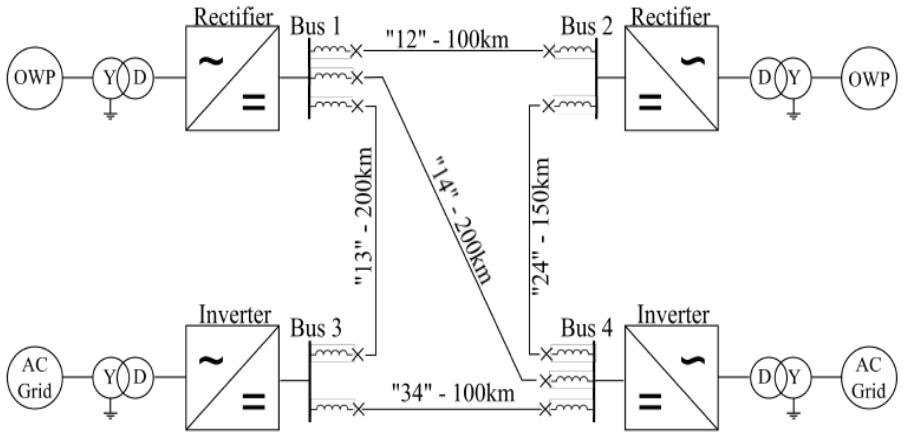




Schultz et al., 2016

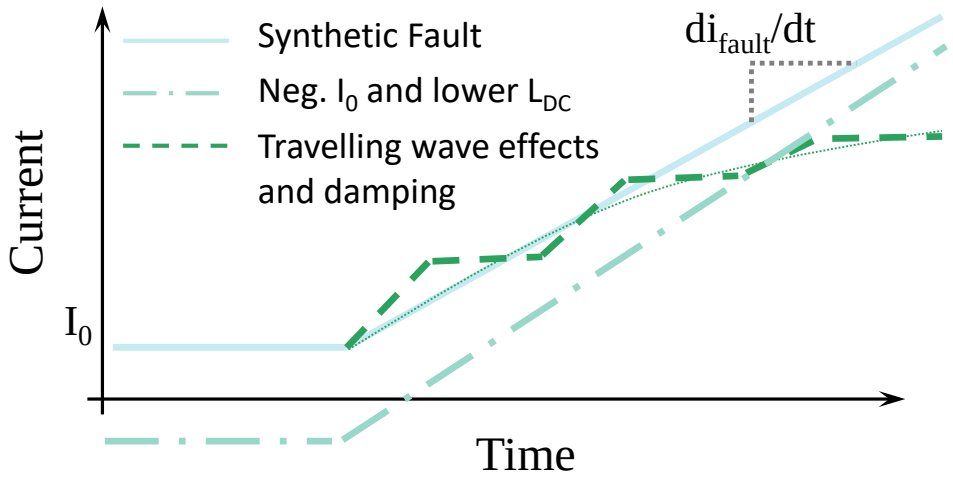
Research:
Behavior of HVDC circuit breaker topologies in grids.

Fault current shapes in HVDC grids can be very versatile and differ from common test cases.



Leterme et al., 2015

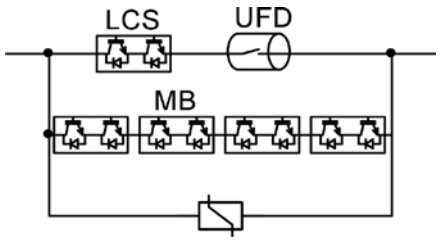
- 4 terminal grid
- ± 320kV
- Multiple fault positions



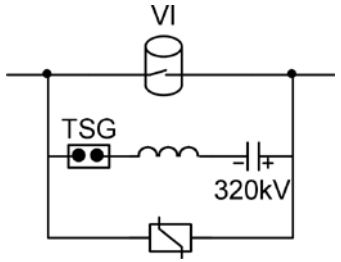
Schultz et al., 2016

Interruption capability depends on breaker topology.

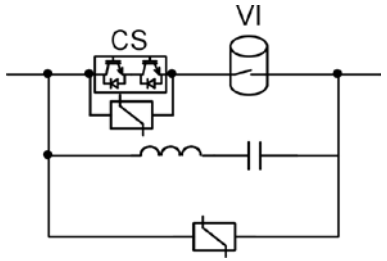
LCS-MB



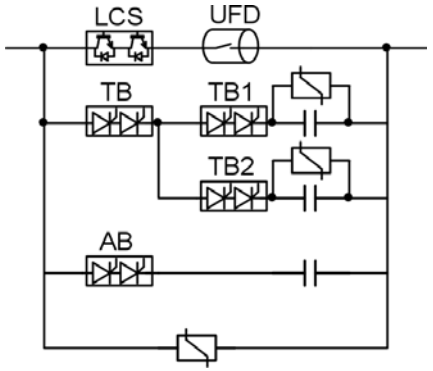
Inj-LC



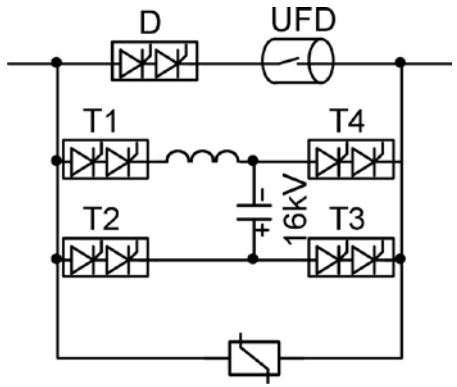
LCS-MB



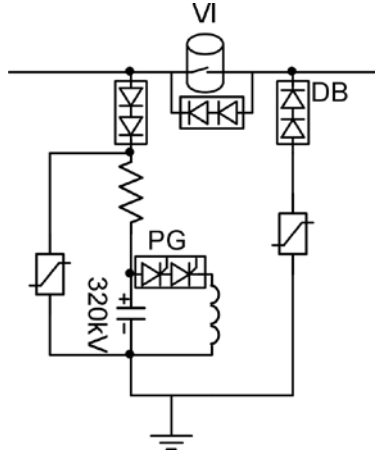
LCS-MB

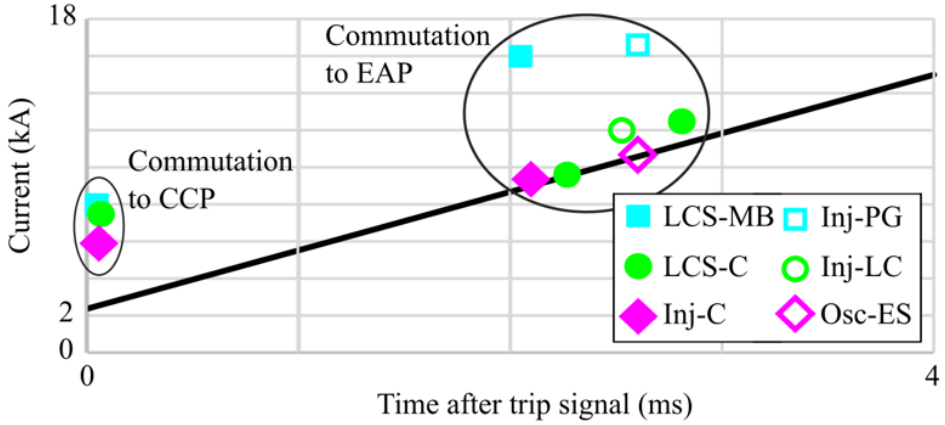


LCS-MB

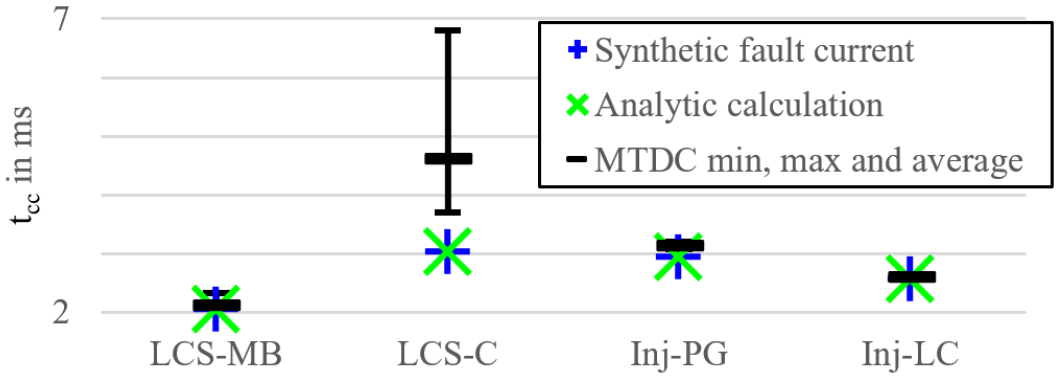


LCS-MB



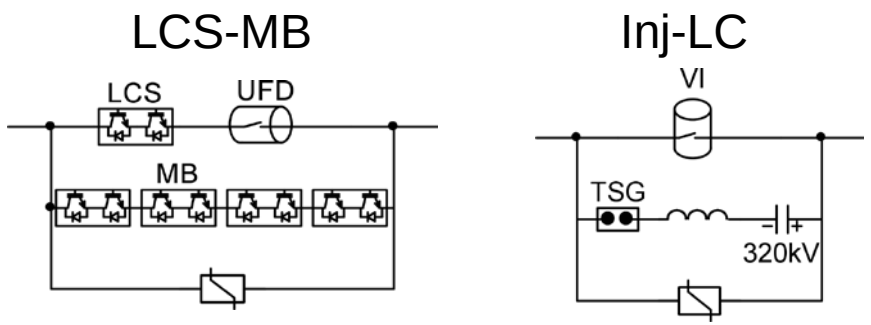


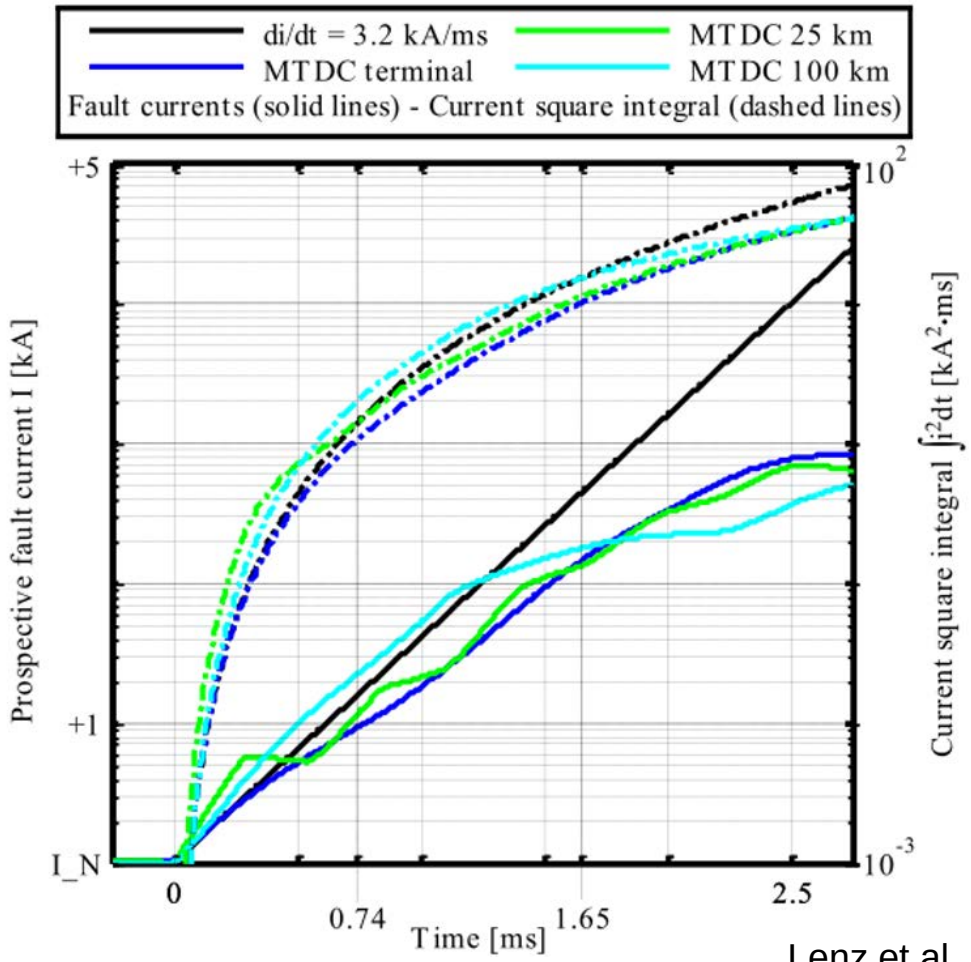
Each topology might have its own «worst case» fault.



Interruption time

Lenz et al., 2017





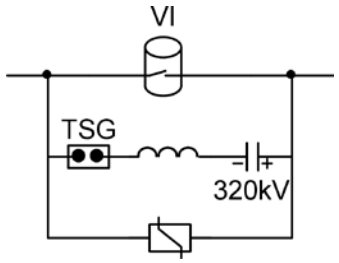
Lenz et al., 2017

Losses over time

Interruption capability of all topologies can be increased using available components or improving mechanical switch.

Topology	$\Delta t_{ccl0,-}$ [ms]	$\Delta t_{ccl0,+}$ [ms]	Key component	Side effect
LCS-MB	+0.01	-	IGBT	Costs
LCS-C*	+0.14	+0.05	C in all branches	Operation time increase
Inj-PG*	-0.04	-0.03	Damping SA	Break time increase
Inj-LC	-	-	LC circuit	Small current interruption

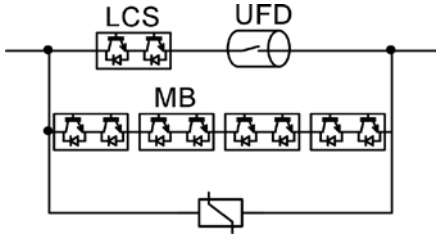
Inj-LC



Increasing speed of mech. switch by 20%

Topology	t_{cc} [ms]	Δt_{cc} [ms]	Optimization for a faster switch
LCS-MB	2.05	-0.40	-
LCS-C	3.04	-0.43	C1: -38 %, C2: -17 %, C3: -30 %
Inj-PG	2.94	-0.45	-
Inj-LC	2.55	-0.50	C: -16 %, L: +21 %

LCS-MB

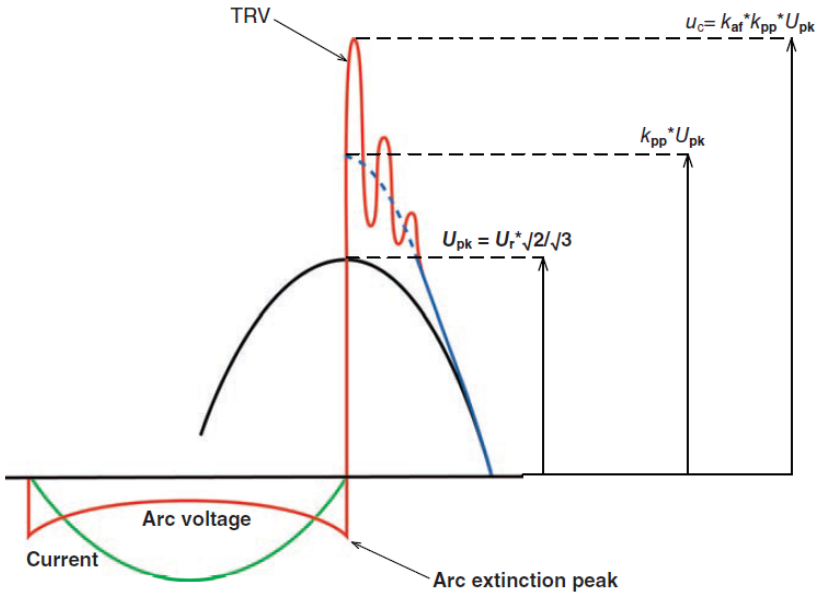


Lenz et al., 2017

Research:
Finding and increasing limit performance of MI in HVDC CB

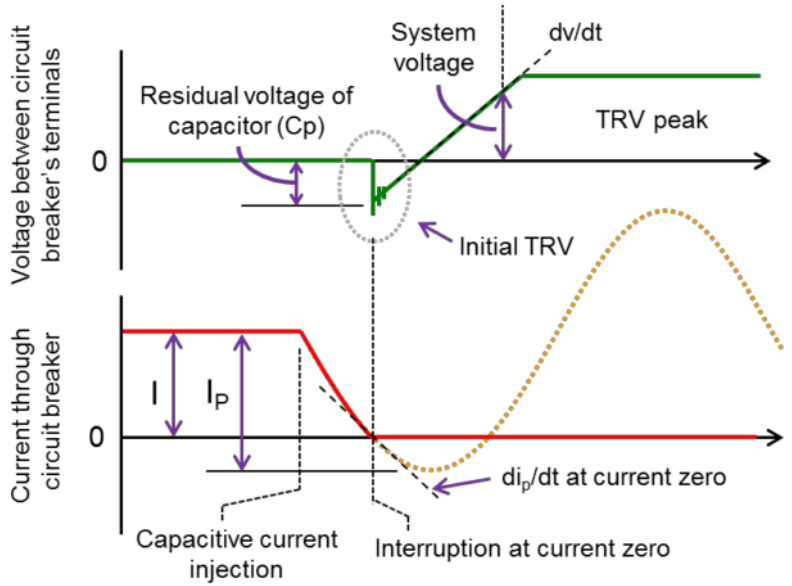
Mechanical interrupters face new challenges in HVDC circuit breakers.

- HVAC
  - grid determines current shape
  - breaker impacts voltage shape
  - «low» time constraints (~100ms)



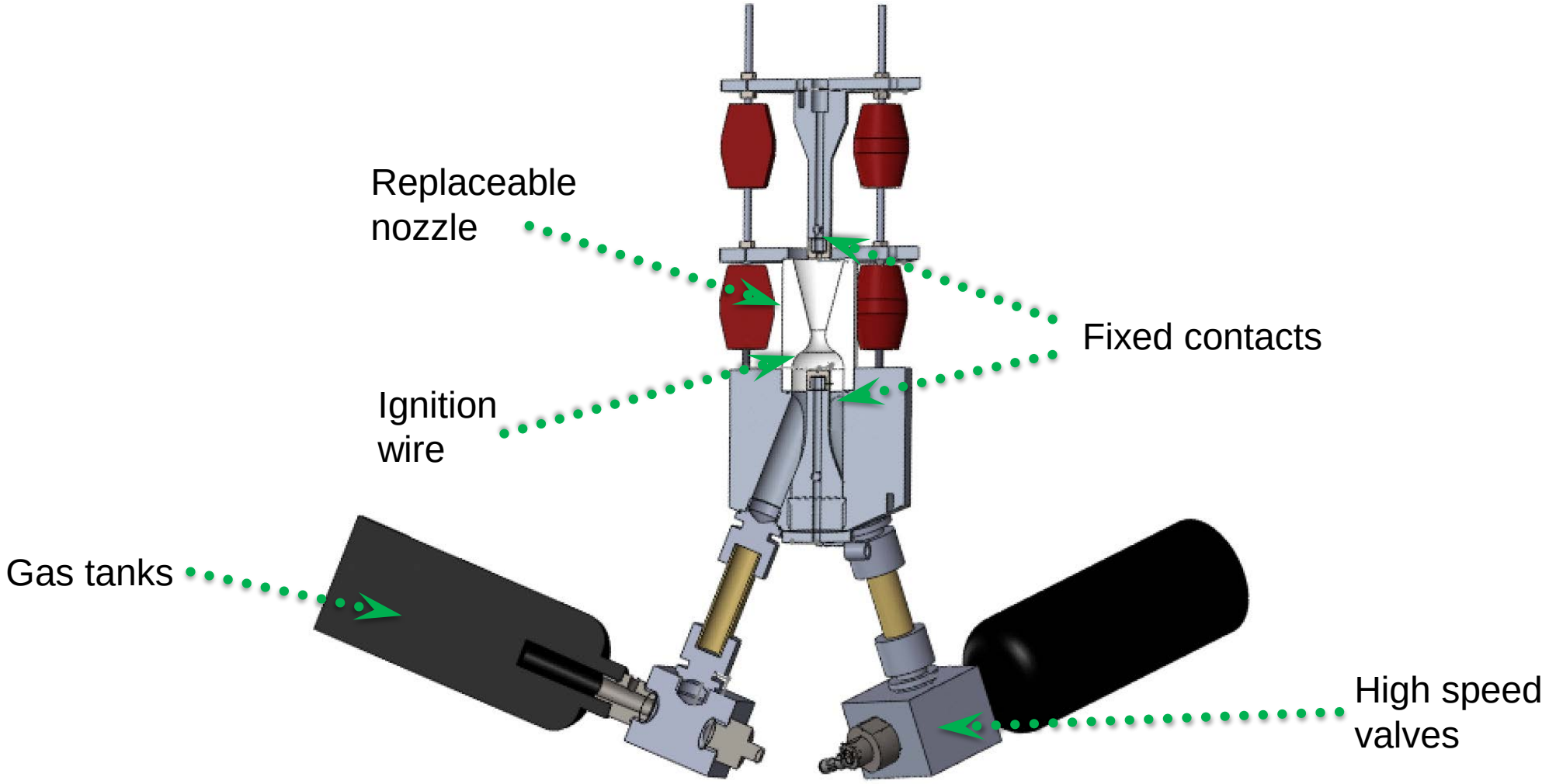
Wiley (Peelo)

- HVDC
  - grid determines fault current, but…
  - breaker determines zero crossing and votlage
  - «high» time constraints (< 10ms)

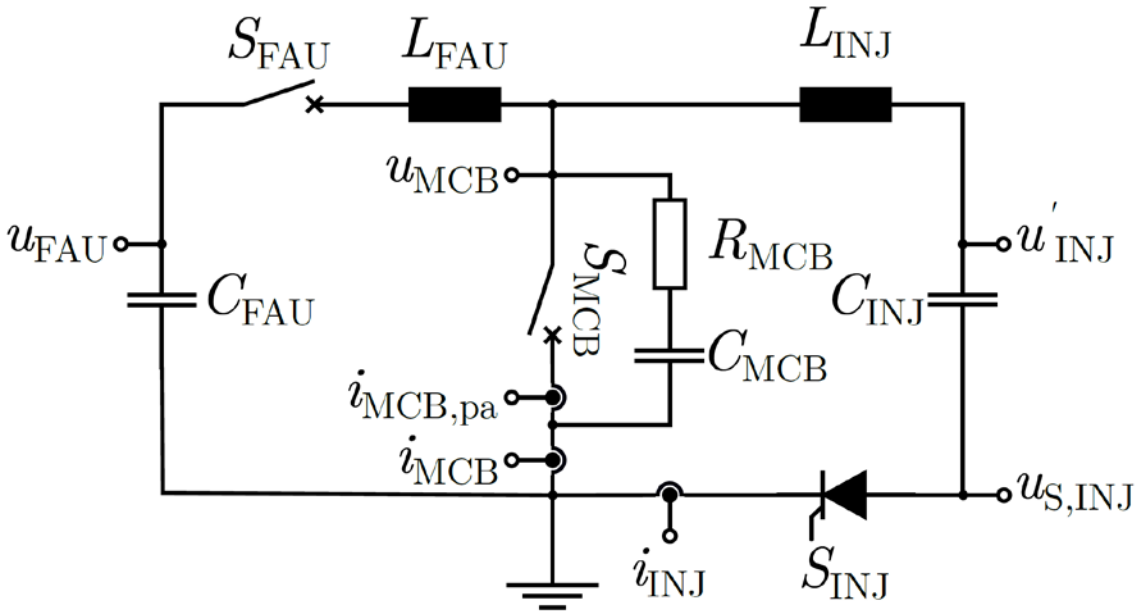


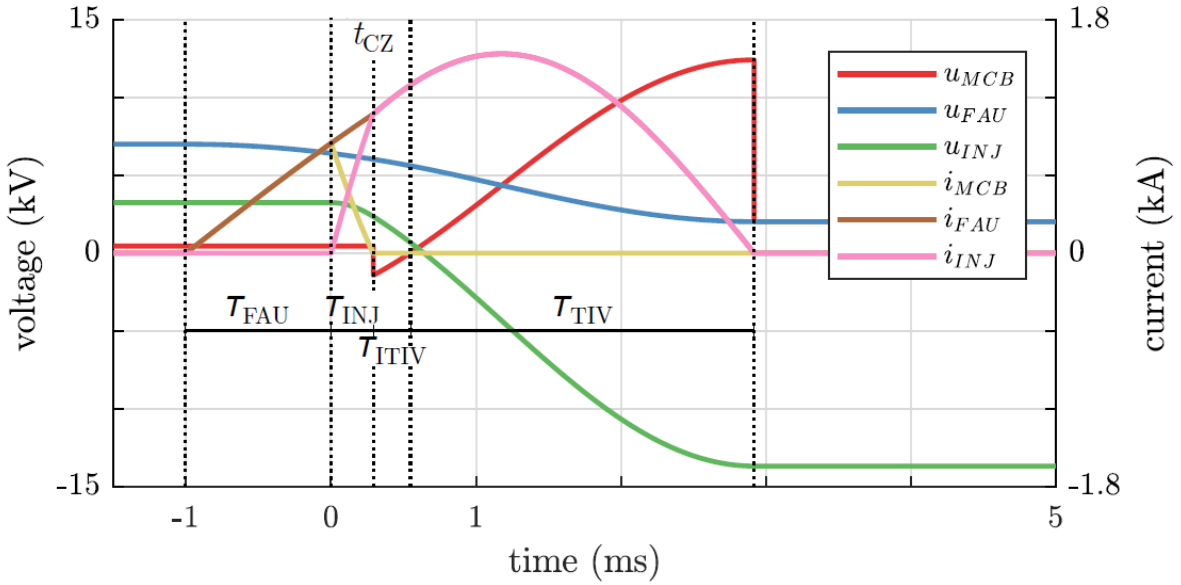
cigre JWG

Device under test (DUT) is a scaled down, simplified model of a gas circuit breaker.



Test circuit: Two LC-circuits create synthetic fault current and injection current.

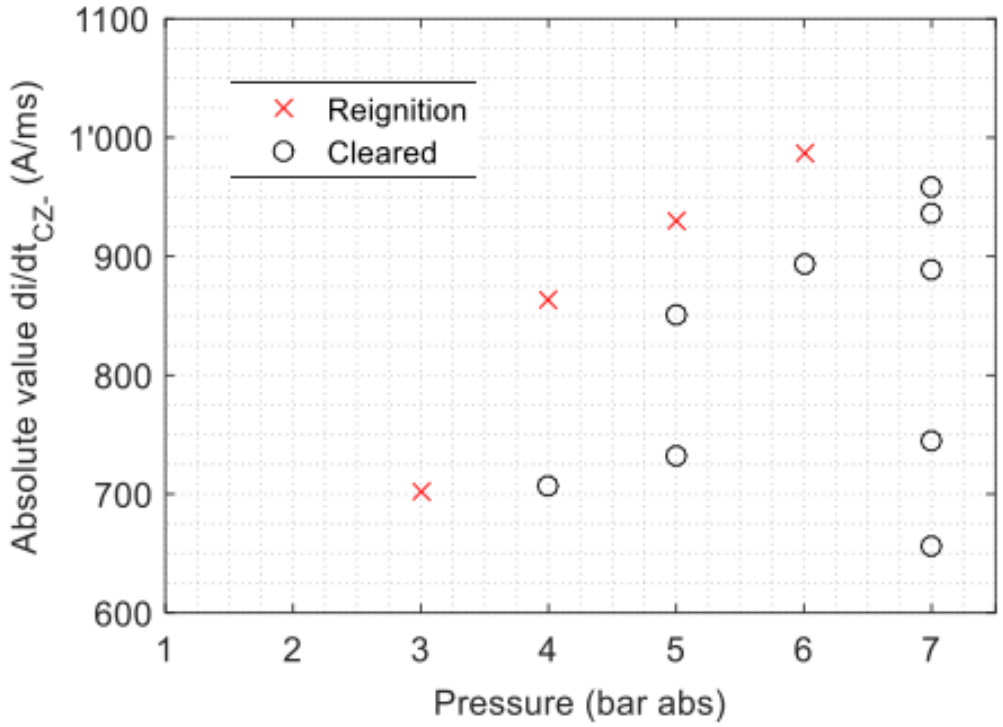




The interruption capability of the custom built DUT has to be investigated.

Parameters that influence interruption capability:

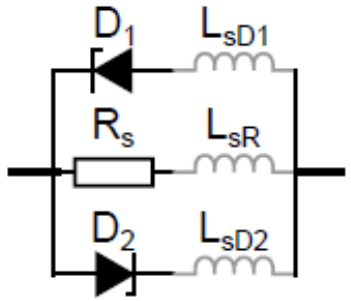
1. Current slope before zero crossing
2. Slope and peak of
    1. Initial transient recovery voltage
    2. Transient recovery voltage
3. Blowing pressure
4. Blowing gas
5. Nozzle shape
6. Contact material
7. …

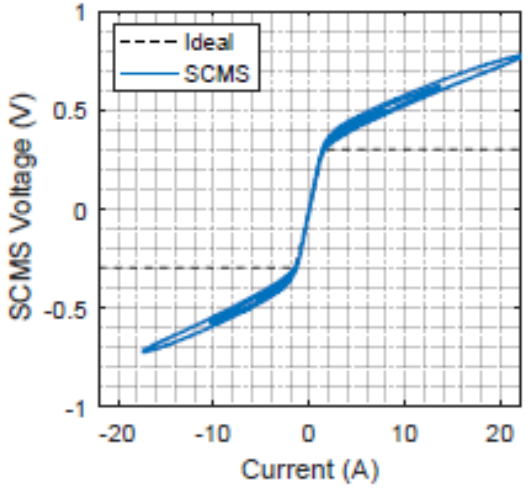


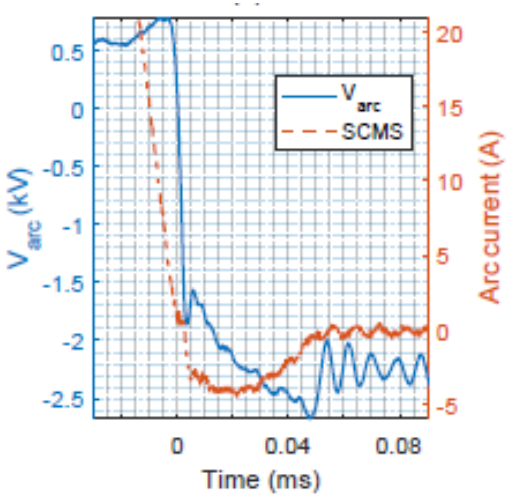
Schultz et al., 2016

Post arc current («reverse recovery») provides information about how close breaker is to its limit.

«Precisely measuring < 1A «pulse»
with duration < 50us after
peak currents of tens of kA»





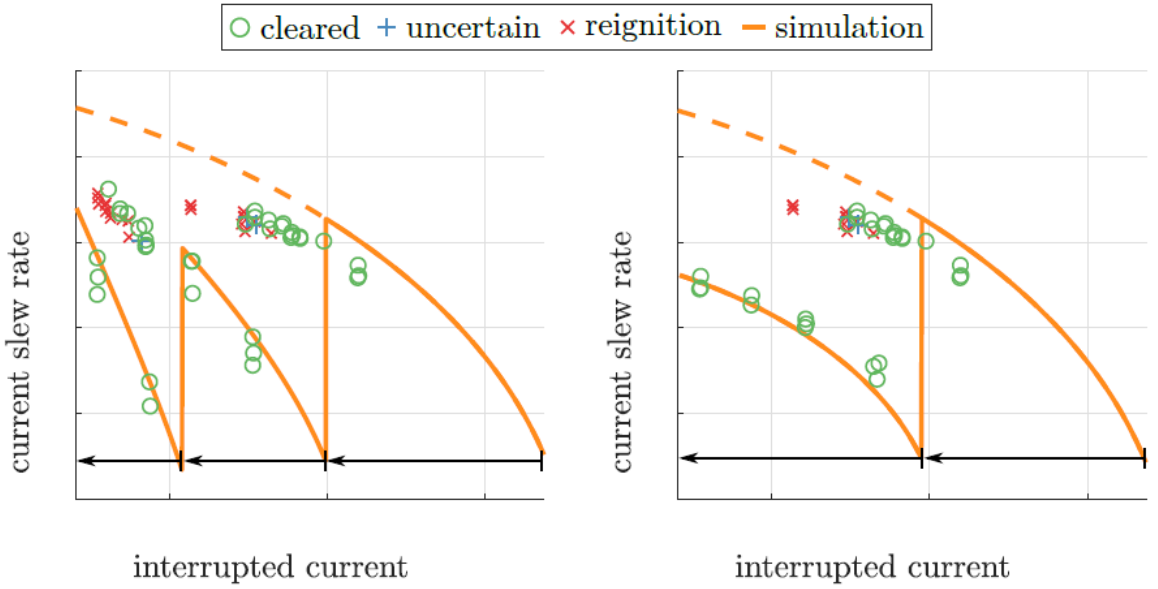


Schultz, 2017

The current injection can be optimized to better utilize interruption capability of the MI.

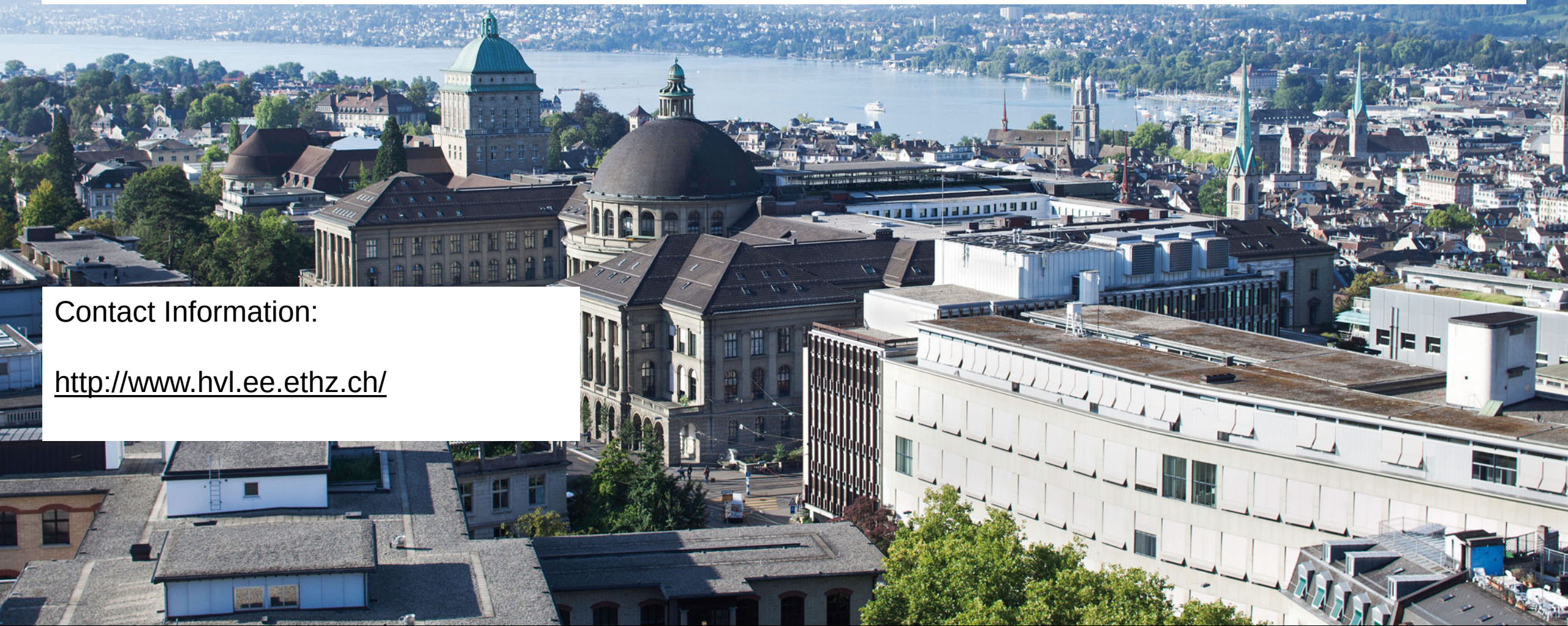
Example: Low current interruption

- Higher stresses for MI
- Tweaking the injection circuit can help to reduce stresses.



Fault current interruption in HVDC networks

Questions?



Contact Information:

http://www.hvl.ee.ethz.ch/