HVDC Circuit Breaker Performance Demonstration

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27-February-2020

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691714.

Outline

- Introduction
  - ✓ HVDC Converter Operation
  - ✓ Fault Condition in HVDC Grids
  - ✓ HVDC Grid Protection – Options
- AC Vs DC Current Interruption
- Testing Methods and Test Circuits of HVDC Circuit Breaker
- Proposed Method and Experiences
- Test Program and Expected Test Result
- Summary

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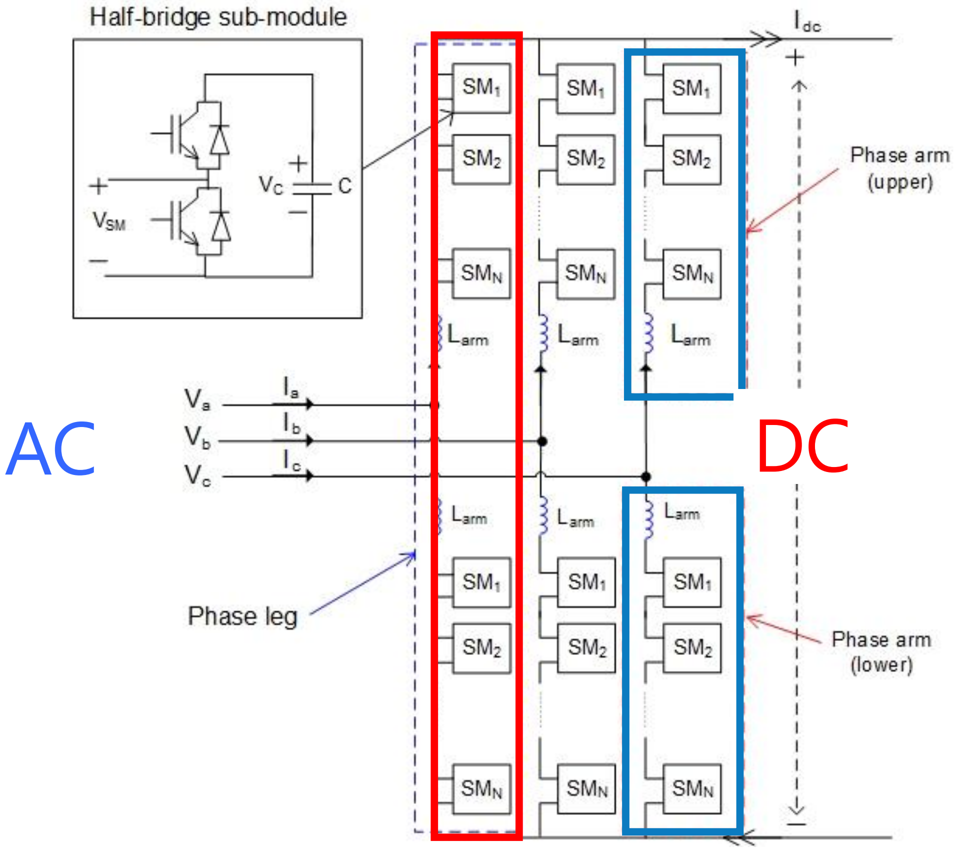
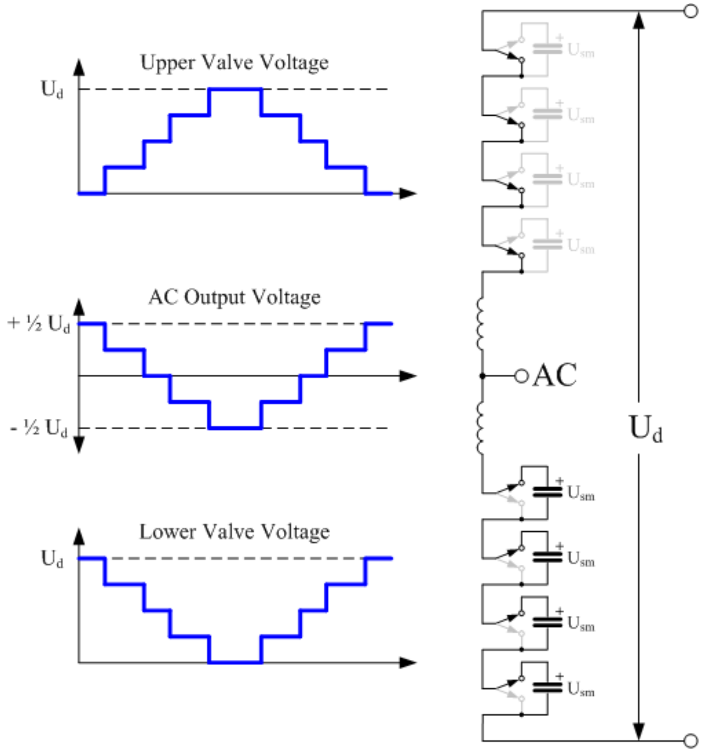
Half-bridge Modular Multi-level Converter (MMC)

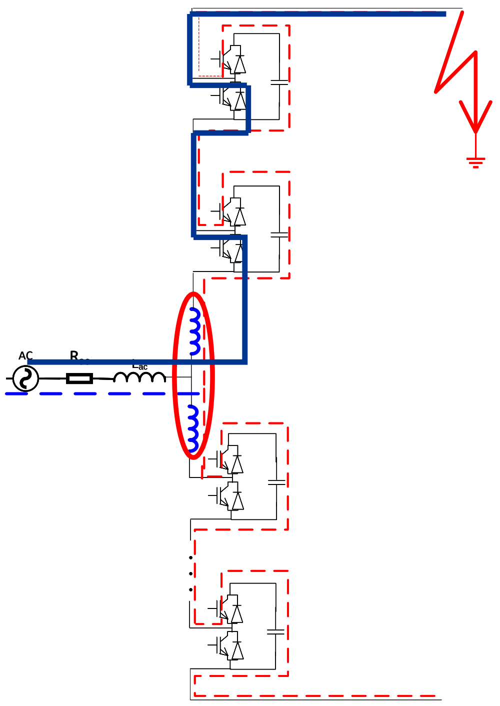
MMC



Operation – one leg



DC Fault – one leg



Source: Wikipedia

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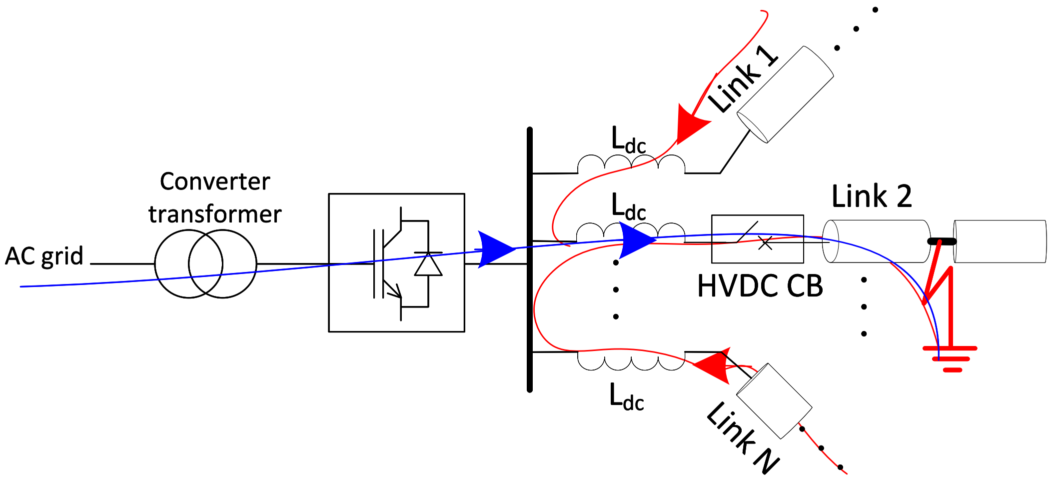
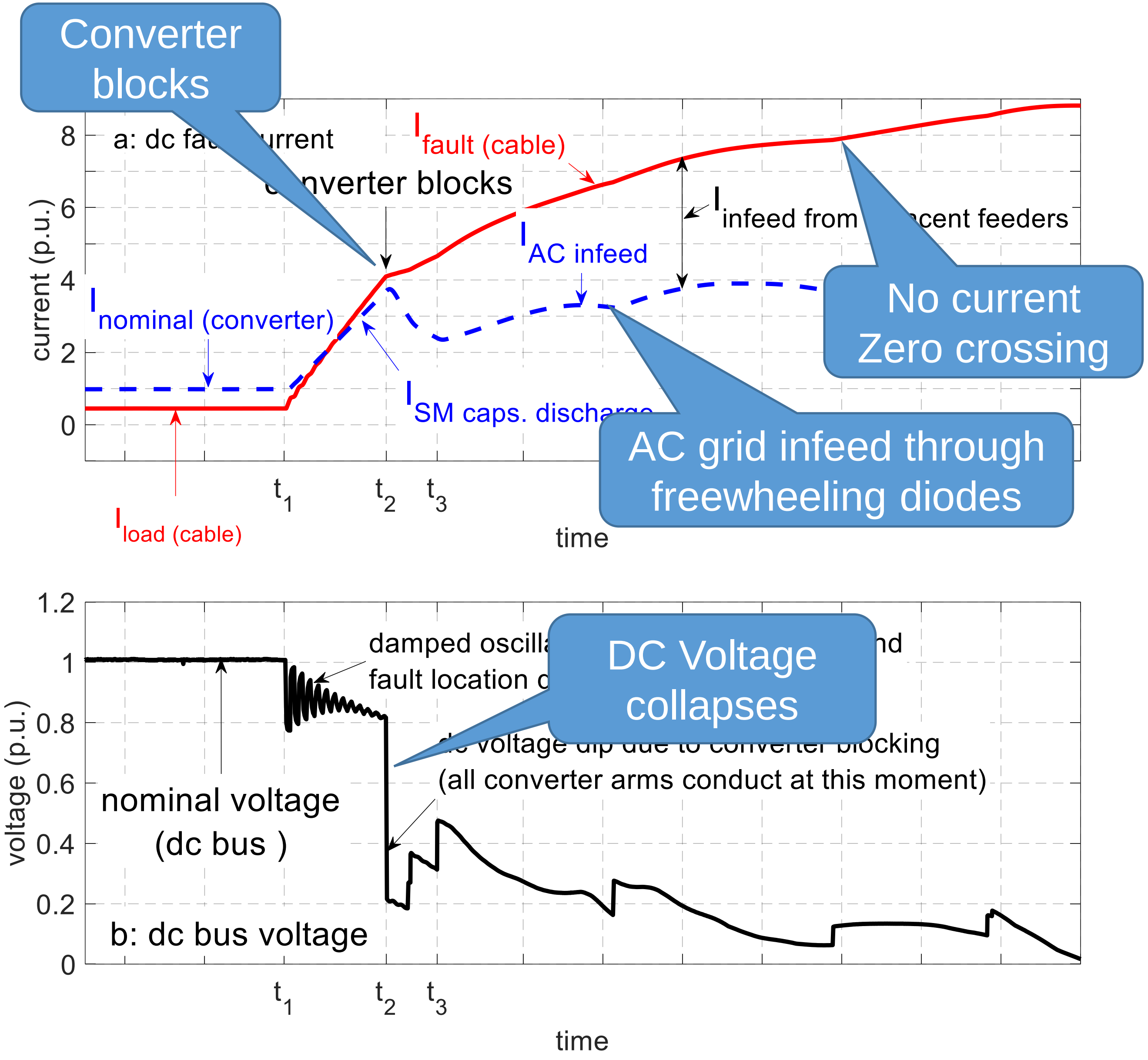
Fault Condition in HVDC Grids





- The fault current grows rapidly
  - No current zero crossing
- Converter blocks
  - Prevents discharge of SM capacitors
  - Protects power electronic components
  - AC side infeed

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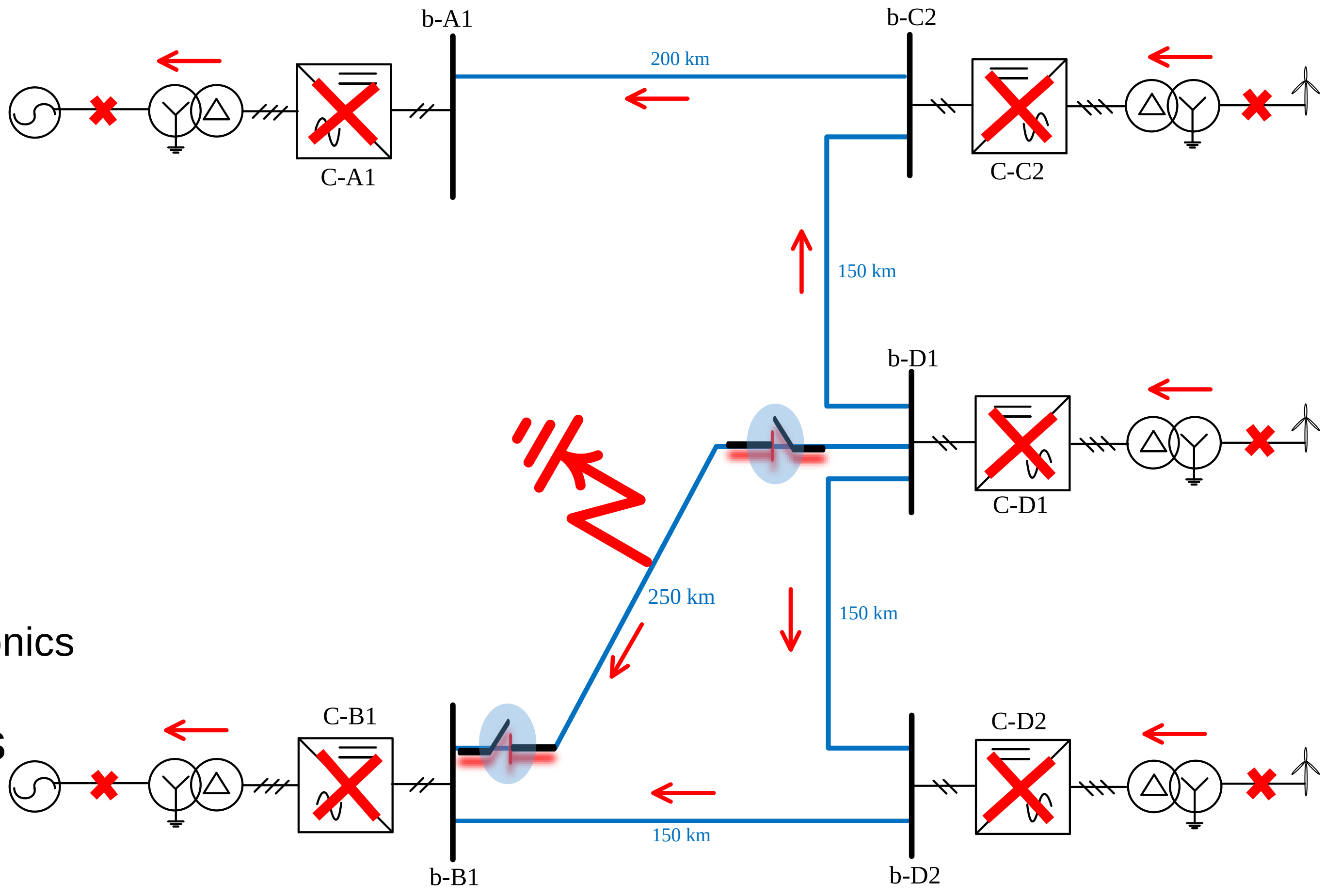
HVDC Grid Protection - Options

1. Using AC Circuit Breakers
   - ✓De-energizes entire DC side
   - ✓Power flow interruption
   - ✓Used in point-to-point connections
2. Using full-bridge converters
   - ✓DC lines and cables de-energized
   - ✓Power flow interruption
   - ✓Losses and the number of power electronics
3. Using HVDC CBs on the DC lines
   - ✓Selective isolation of fault
   - ✓Power flow in the healthy part



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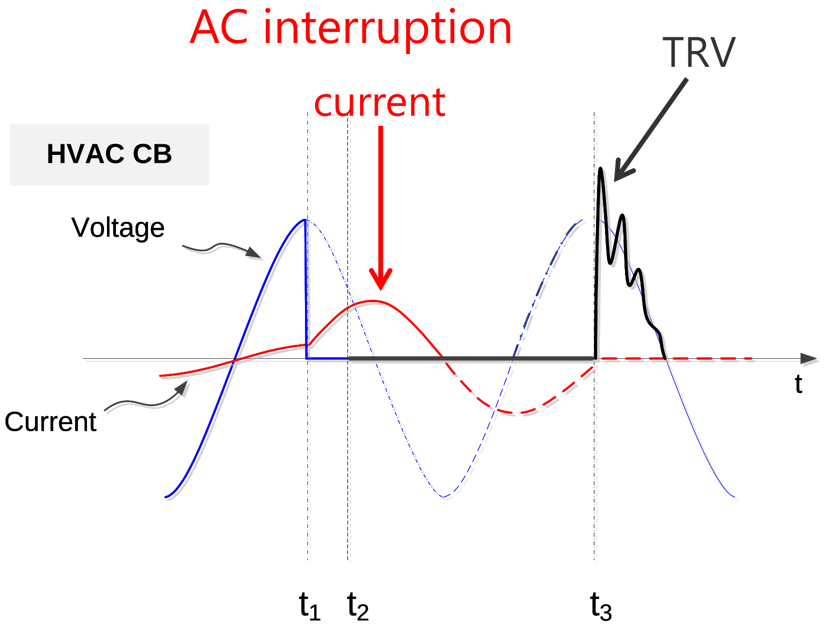
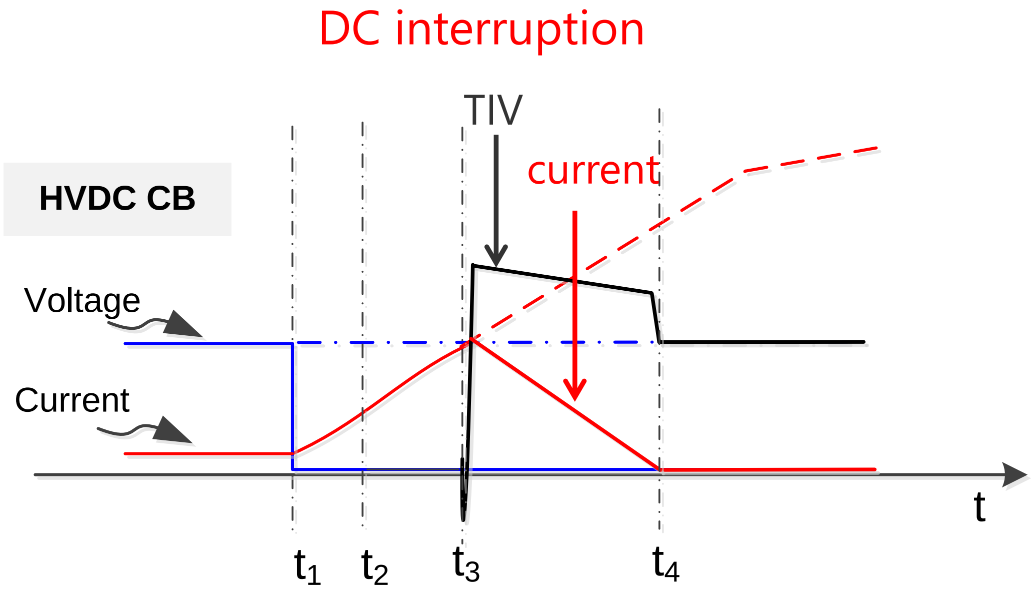
AC Vs DC Current Interruption





- AC CB passive –system determines short-circuit current
- System imposes TRV
- Synthetic test method can be applied

- DC CB is active - determines the peak current
- CB determines the TIV
- Needs MW to test

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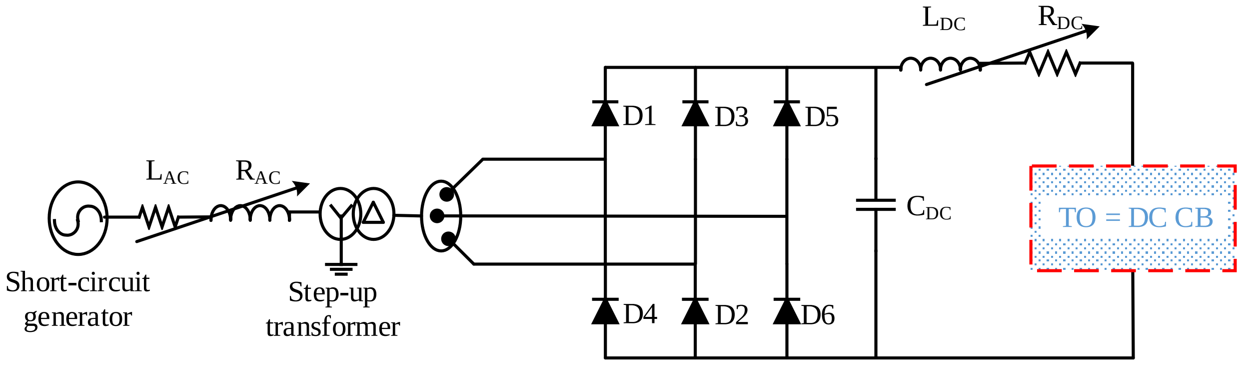
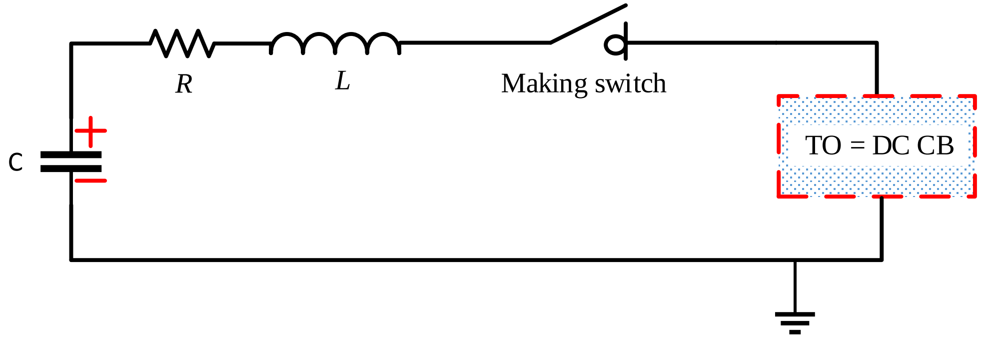
Test Methods and Circuits

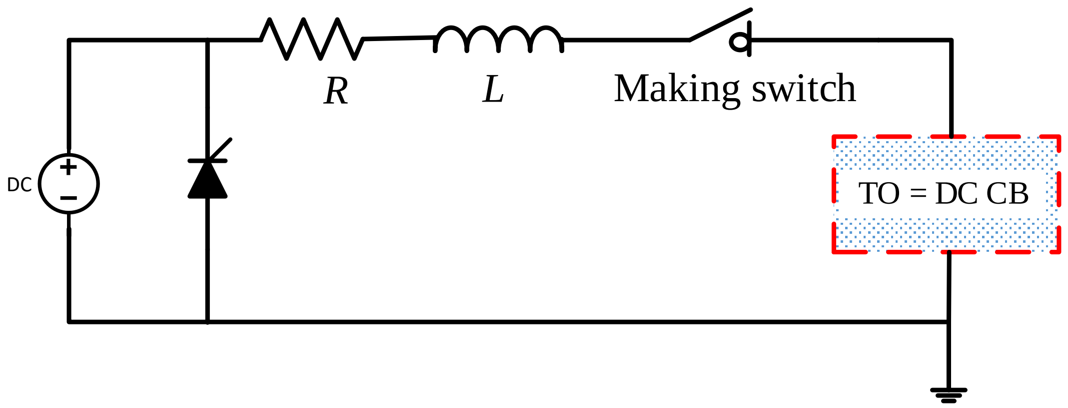
Rectifier



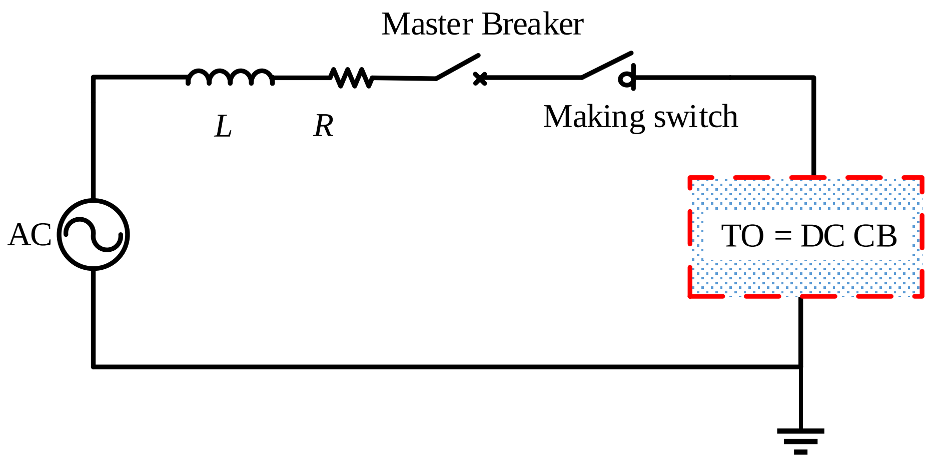
Charged capacitor



Charged reactor



AC source



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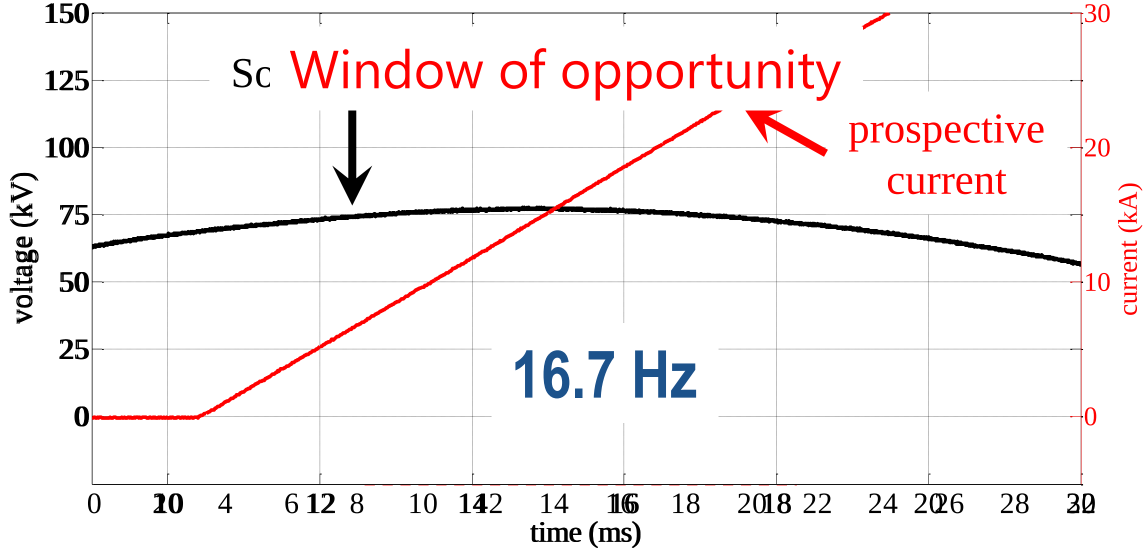
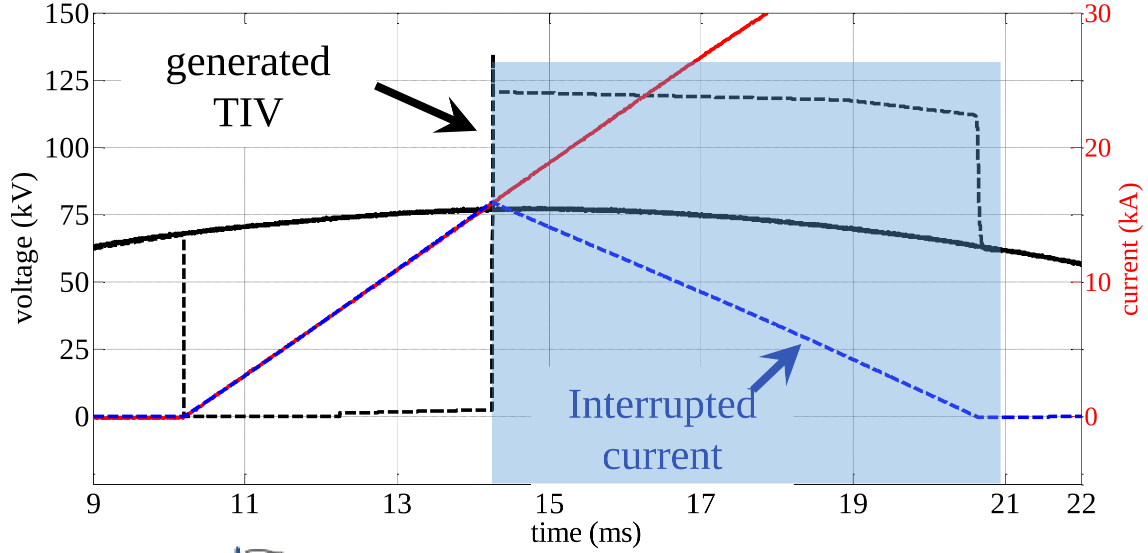
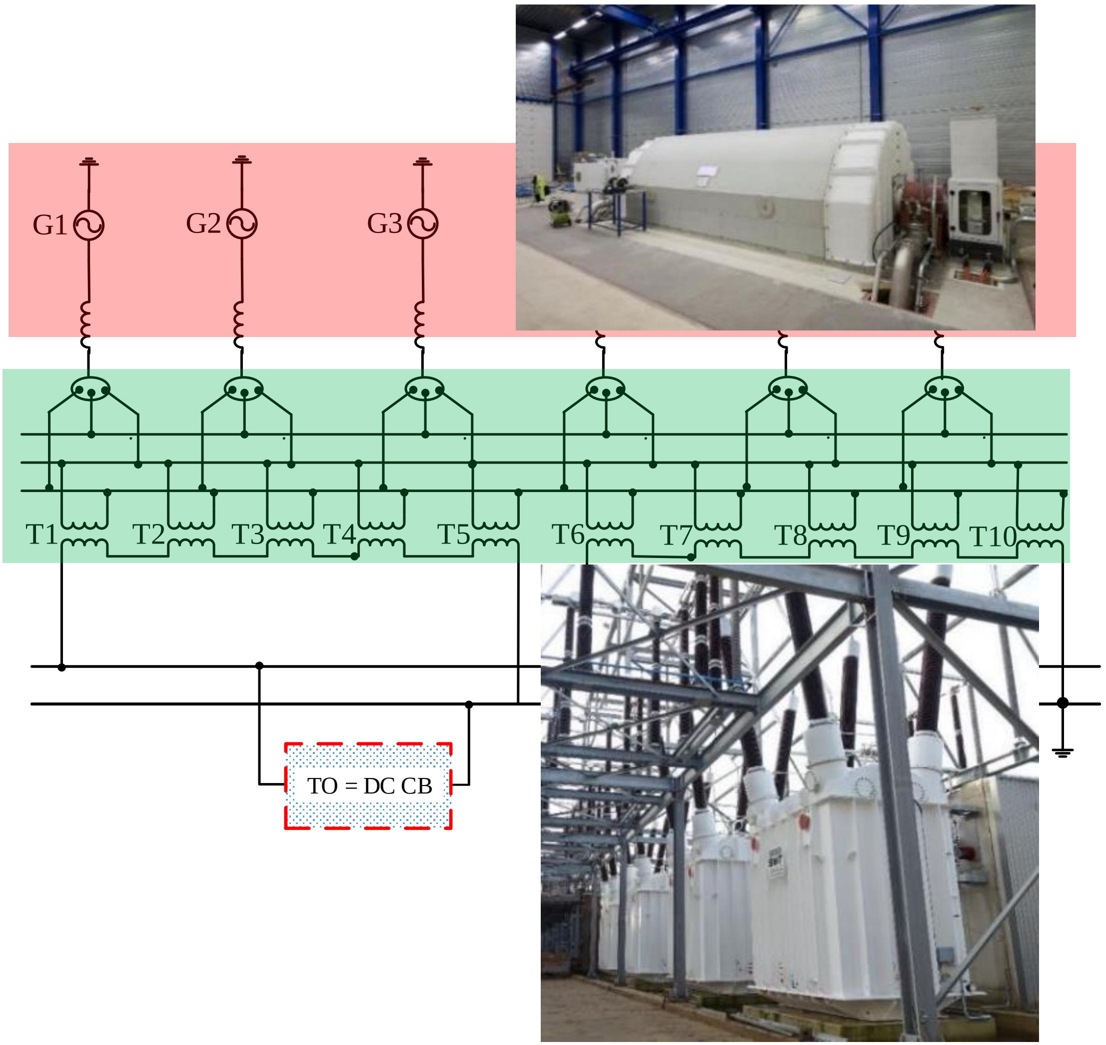
Proposed Method - Using Low Frequency AC Generators





6 Short-circuit Generators



10 Step-up Transformers

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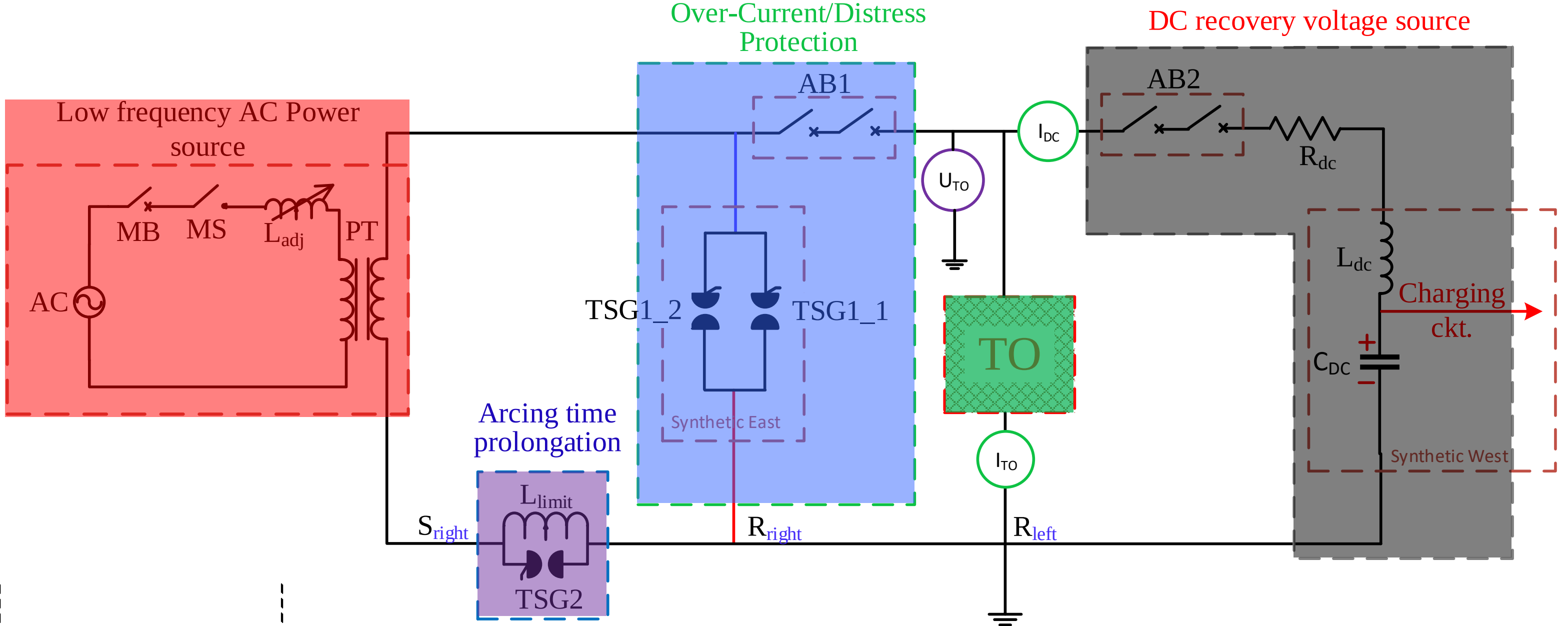
Test Circuit for HVDC Circuit Breakers – Critical Aspects

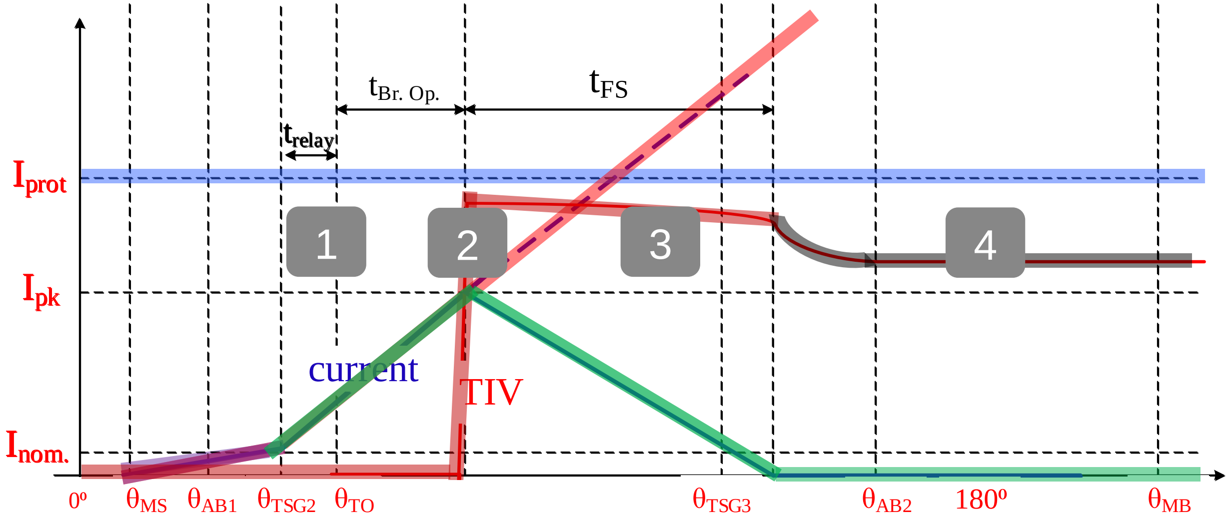
Power Source

Protection

Arc time prolongation

DC recovery voltage





Four Critical Stages of Current Interruption

1. Internal Current Commutation
2. The generation of transient interruption voltage
3. Energy absorption
4. DC voltage withstand

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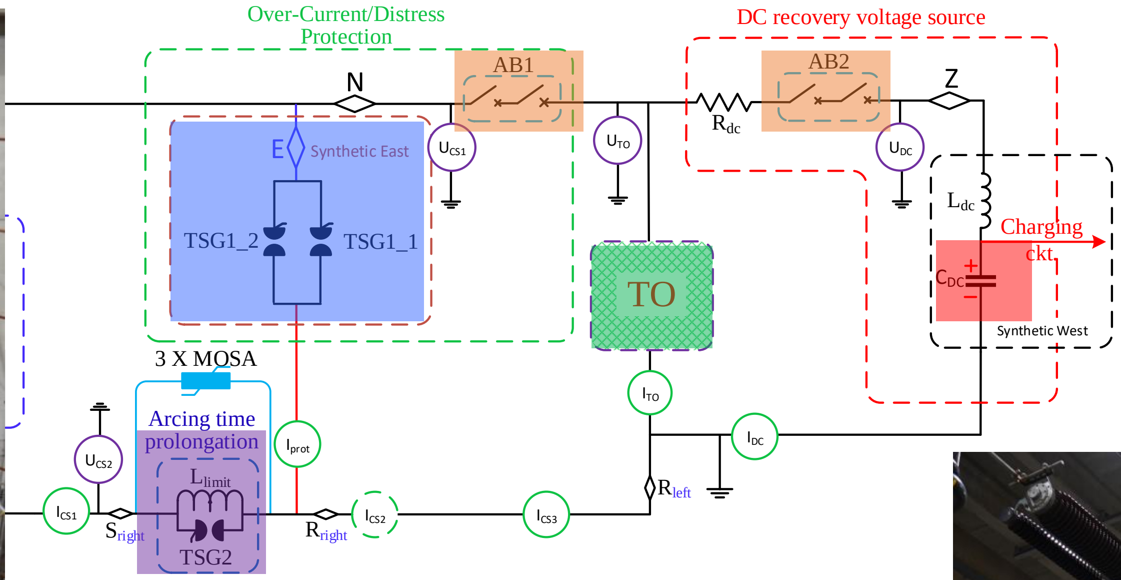
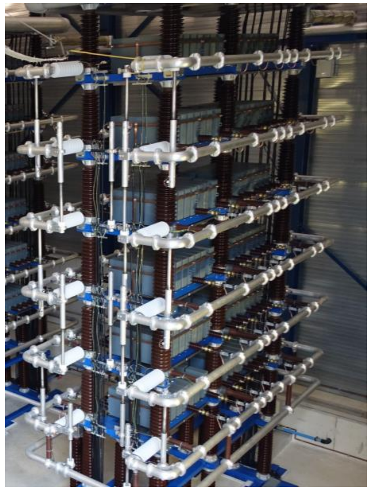
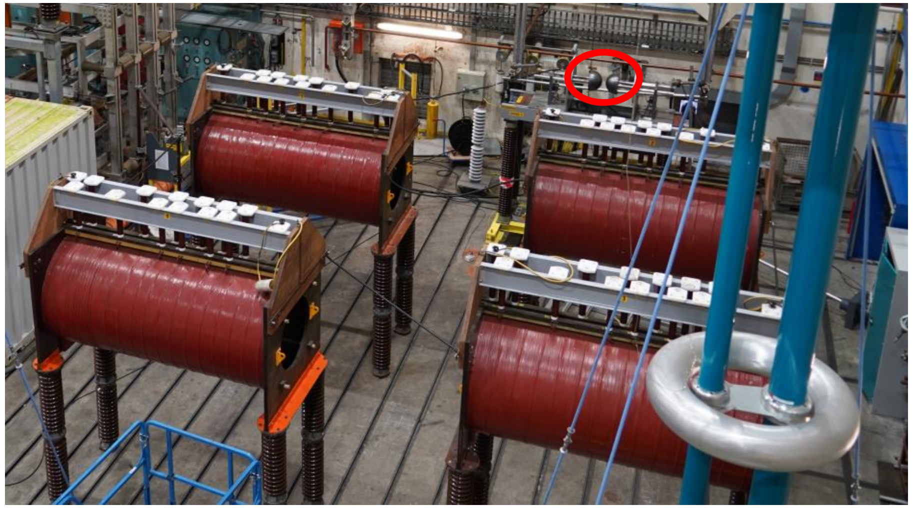
Complete Test Circuit for HVDC Circuit Breaker → components







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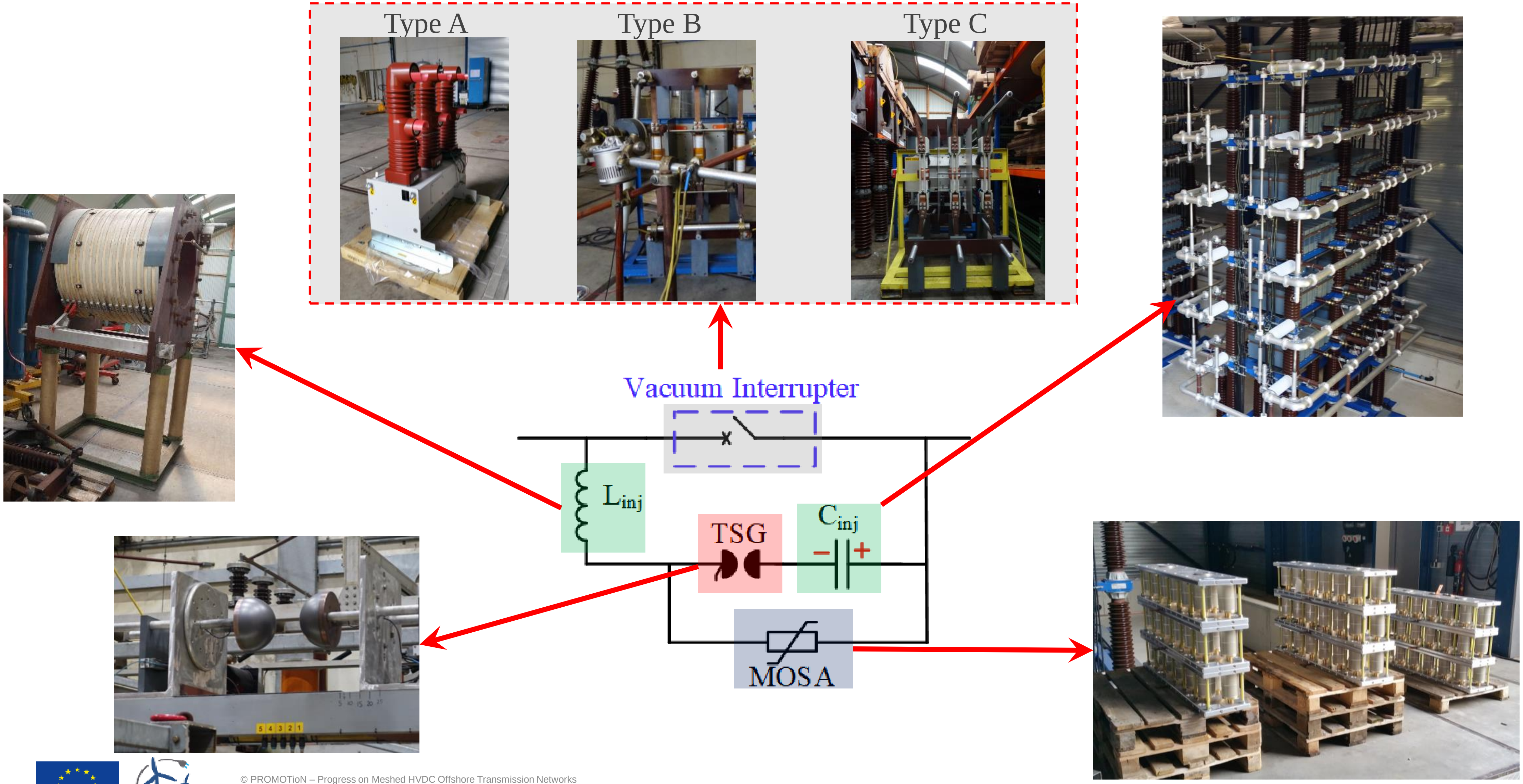
Experimental DC CB setup → Configuration and Main Components



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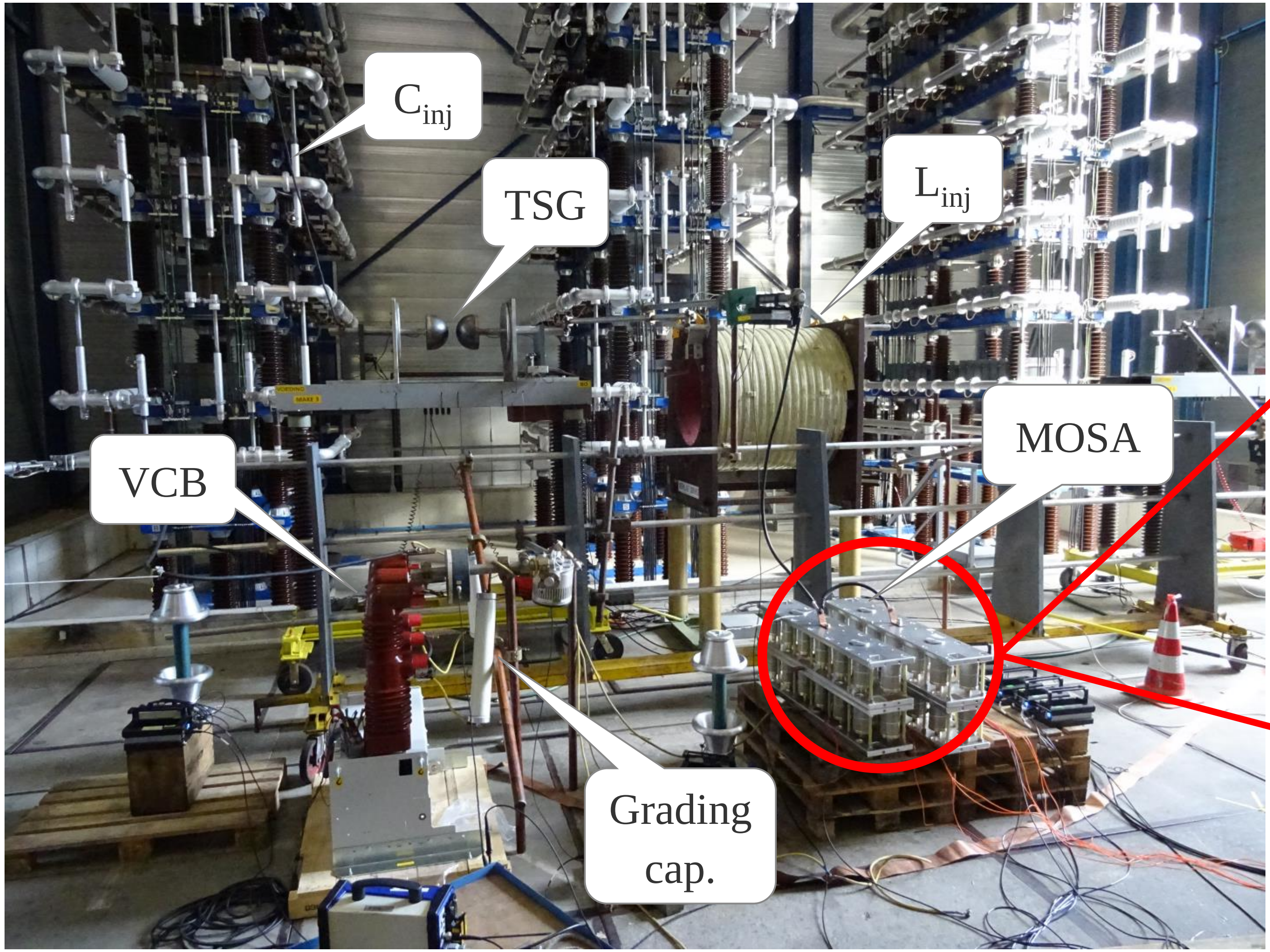
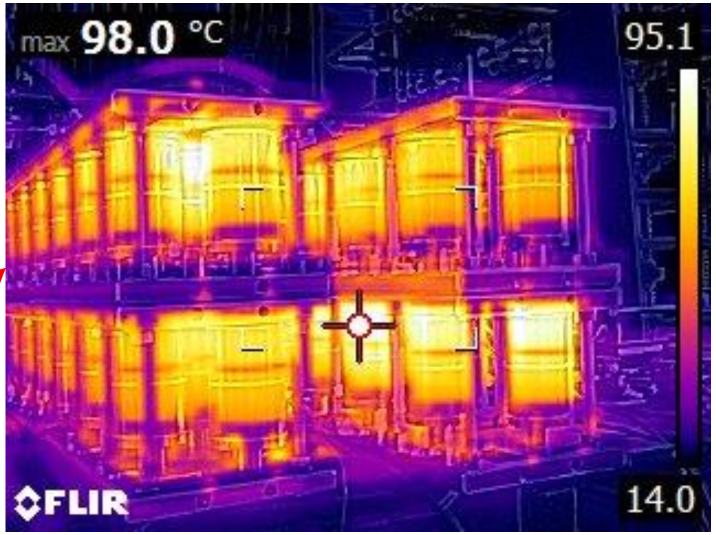
Experimental Investigation





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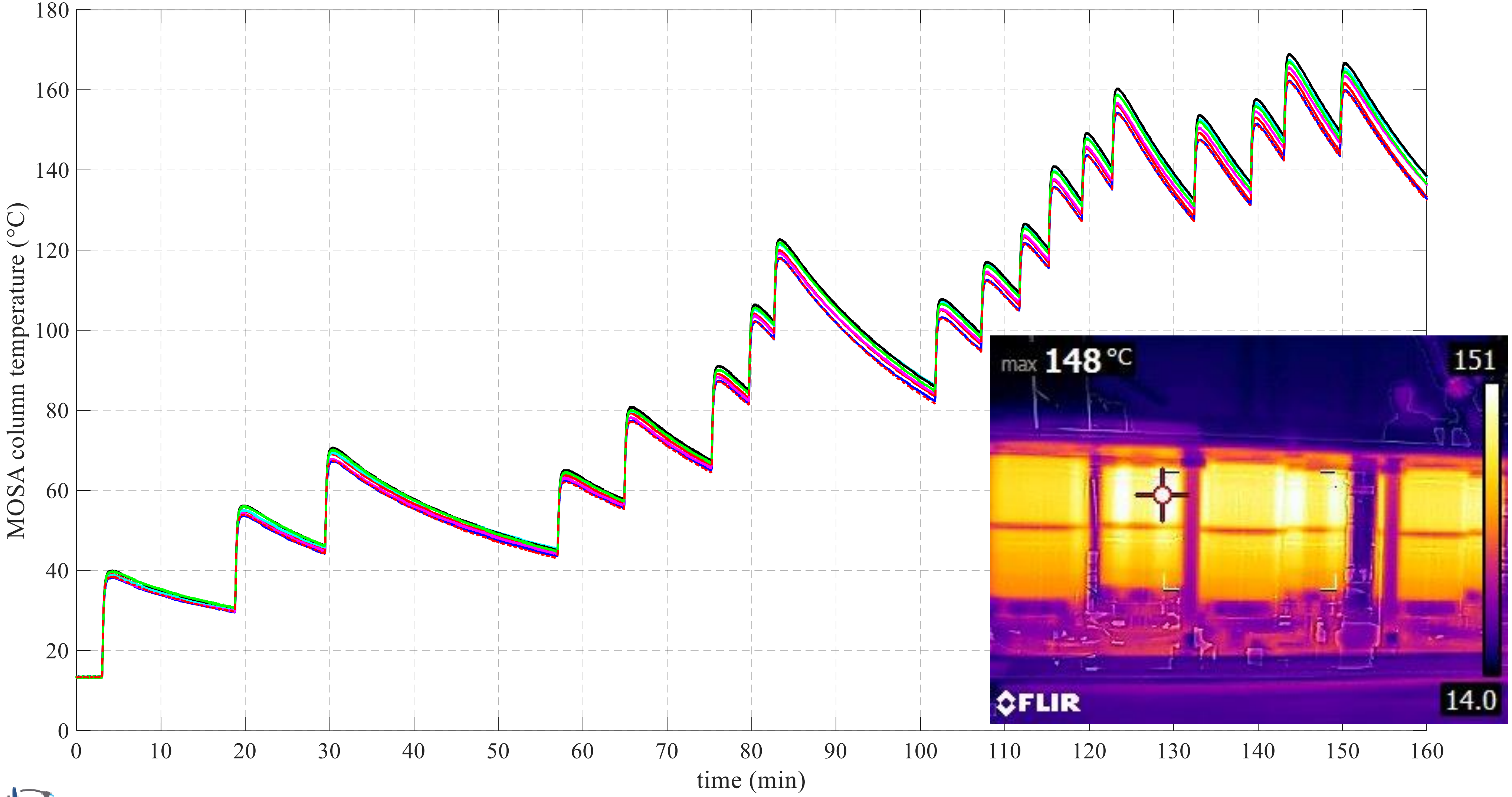
MOSA temperature measurement over successive energy injection



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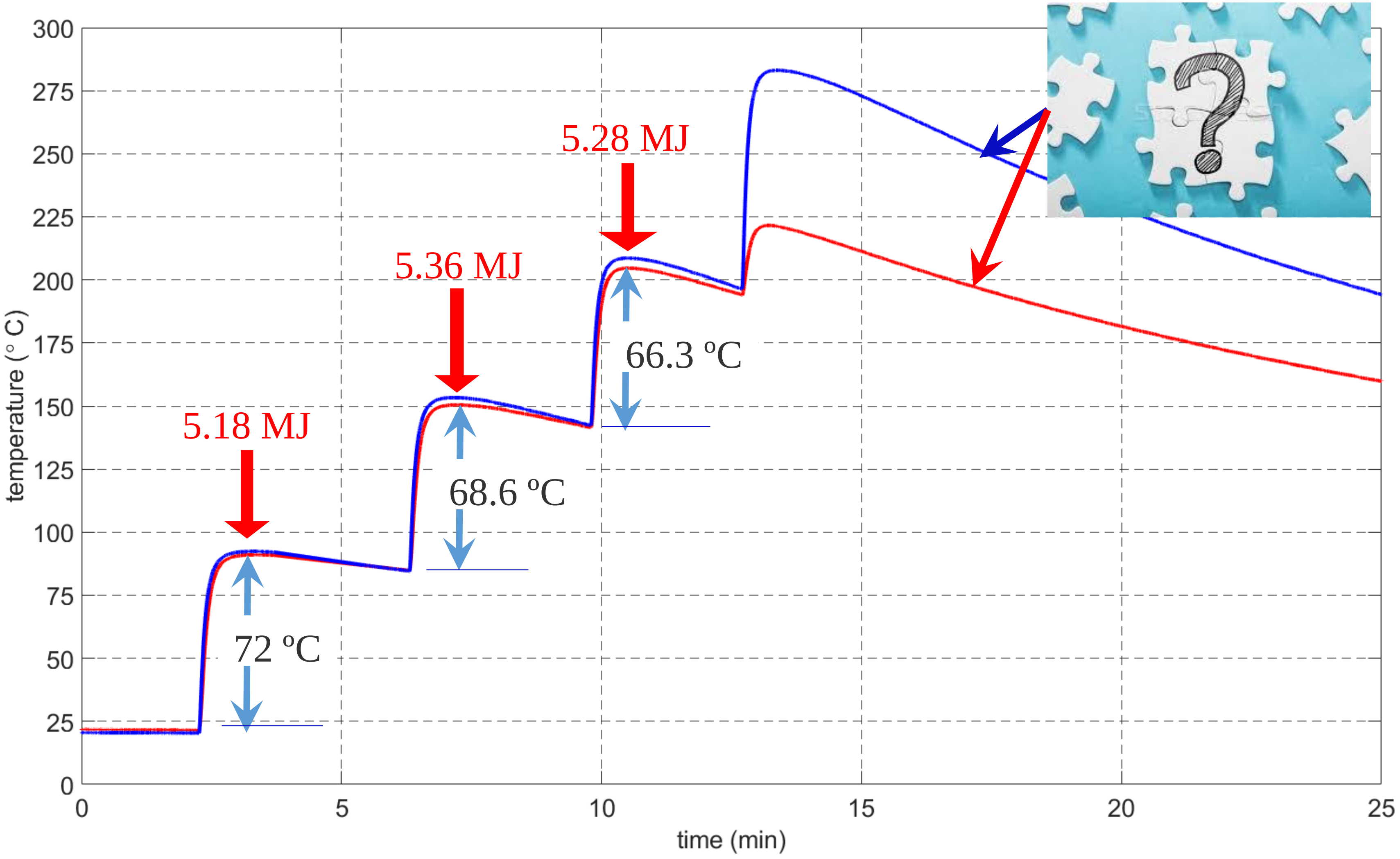
Temperature Measurement – High energy injection



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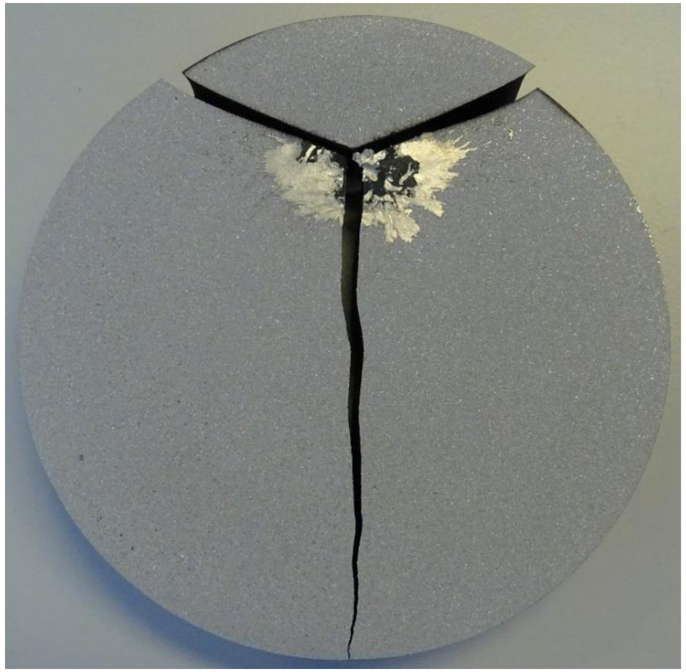
Test Results → Visual Inspection

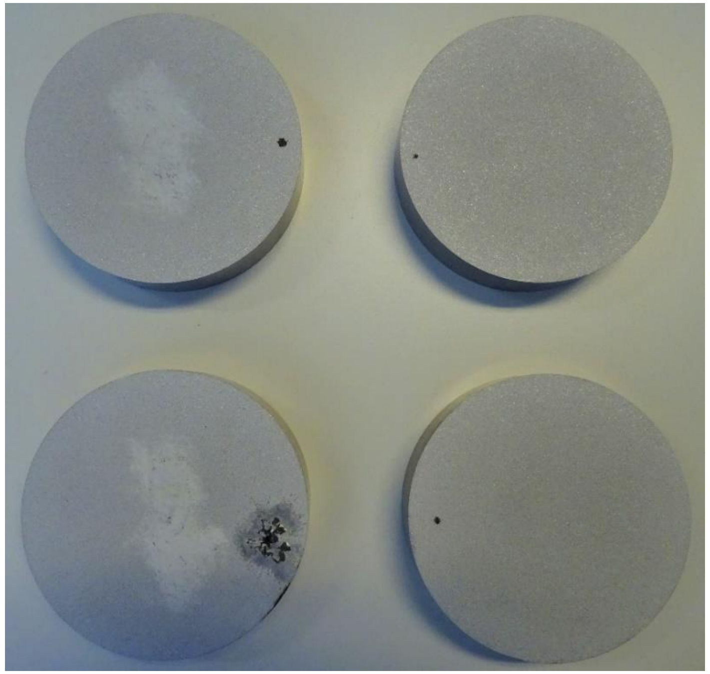
Module 2 – Cracking(s)

- Total energy before failure = 1.3 MJ
- Energy per volume = 107 J/cm^3
- Only one MO varistor cracked



Module 1 – Puncture(s)

- Total energy before failure = 3.56 MJ
- Energy per volume = 293.78 J/cm^3
- Multiple MO varistors punctured



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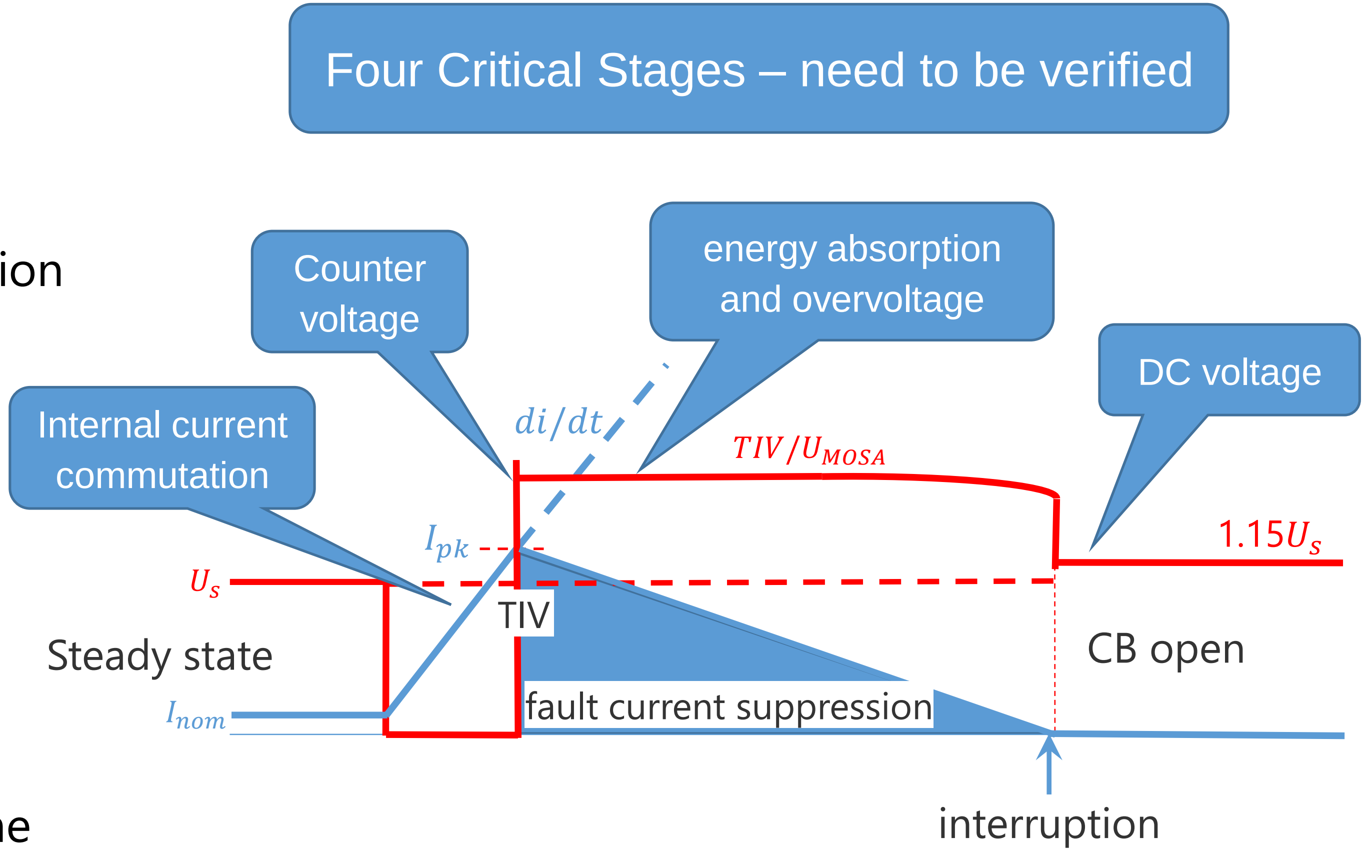
Stresses During DC Current Interruption

- Breaker data needed:
  - U_s = System voltage
  - I_{pk} = Peak interruption current
  - ΔT_{ic} = internal current commutation
  - TIV



  - ΔT_{fs} = fault current suppression time
  - Energy = Energy absorption

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Proposed breaking test requirements – Test program

Name	Current	Breaking test	#
TC10+	10% of rated continuous current	2 tests in positive current direction	2
TC10-	10% of rated continuous current	2 tests in negative current direction	2
TC100+	100% of rated continuous current	2 tests in positive current direction	2
TC100-	100% of rated continuous current	2 tests in negative current direction	2
TF100+	100% of peak fault current	2 test at specified energy absorption*, positive current direction	2
TF100-	100% of peak fault current	2 test at specified energy absorption*, negative current direction	2
TDT+	TBD	2 test at rated fault current suppression time**, positive current	2
TDT-	TBD	2 test at rated fault current suppression time**, negative current	2
	*: Specified energy absorption based on specified value of energy absorption (MJ) of the test-object **: Rated fault current suppression time based on *Us, UMOSA, ΔTic, Ipk*, as would be present in service		
	All tests are single opening operations		
	In all tests, *Us* (considering 10-15 % overvoltage) will be supplied during 300 ms		

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Summary

- Testing so far focuses on proof of concepts – not on complete stress
- Four critical stages in fault current interruption:
  - ✓ Fault current rise – breaker operation time
  - ✓ Commutation and counter voltage – magnitude and duration of TIV
  - ✓ Energy absorption – stresses on internal components
  - ✓ DC voltage stress across open breaker – sufficient duration
- Adequate testing should represent each of these stages, stressing different subcomponents at each stage of current interruption process
- The use of multiple AC generators running in low-frequency offers a one-stop test possibility – developed and verified in PROMOTioN project

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PROMOTioN
PROGRESS ON MESHED HVDC OFFSHORE TRANSMISSION NETWORKS

Thank you!

Questions?

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