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HVDC GRID PROTECTION

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TU Delft – workshop
Power System Integrity – Bring AC and DC together
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Outlines

- Introduction
- AC protection approach to HVDC
- New protection requirements for HVDC grids
- DC protection approach to HVDC grids
- DCCB operating principle
- System impacts on DCCB design
- Conclusions

Introduction

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DC grids are emerging as a technology “natural selection” due to co-location of new loads and generation and requirements for cost effective solutions esp offshore

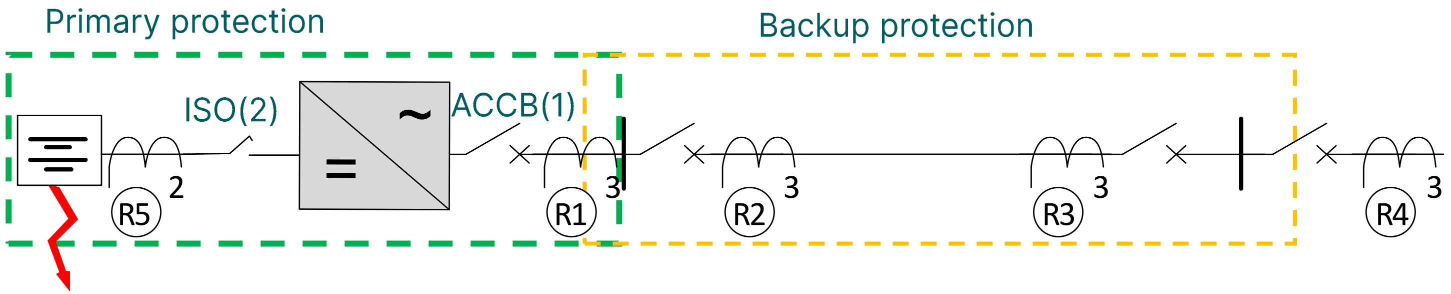
- Ambitious targets for offshore wind (and wave) capacity esp. in Europe by 2050
- Electrification of oil and gas platforms
- Hydrogen production for clean maritime

Elemental research and development work has been done during the last decade

- DCCB demonstrators – GE DCCB prototype as part of EC project Twenties in 2013

Today – it’s “System of Systems” time

AC protection approach to HVDC

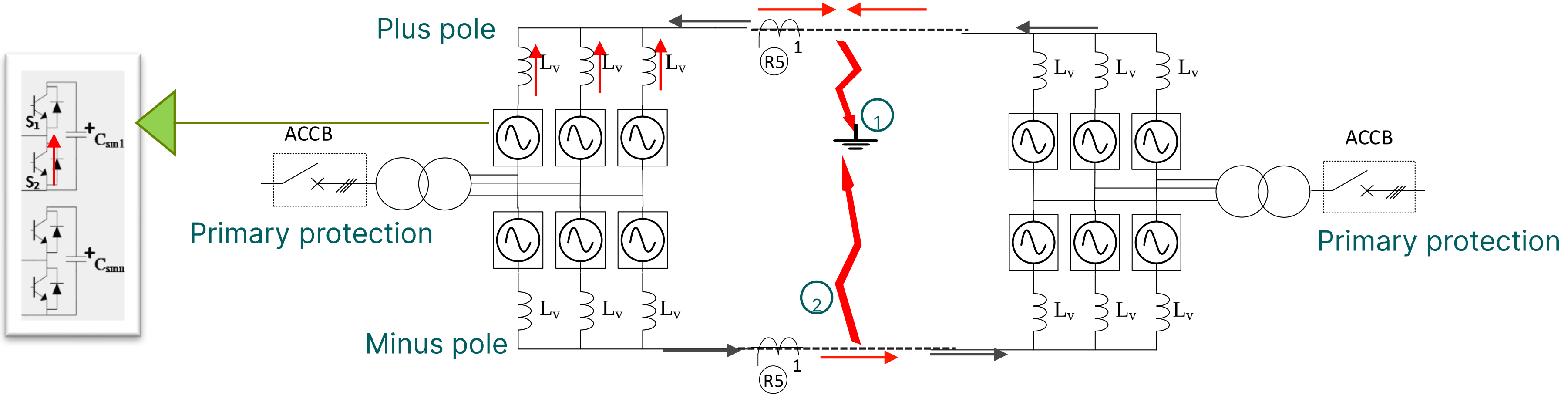


Detect the fault (R5) → Block converter → Trip ACCB (1) → Isolate the fault (ISO(2)) → Reclose ACCB (1) → Deblock converter

Assuming converter can operate as STATCOM in this example

AC protection approach – fault clearing

- S2 Diode Conducts
- Fault current uncontrolled



Detect the fault on OC (R5)

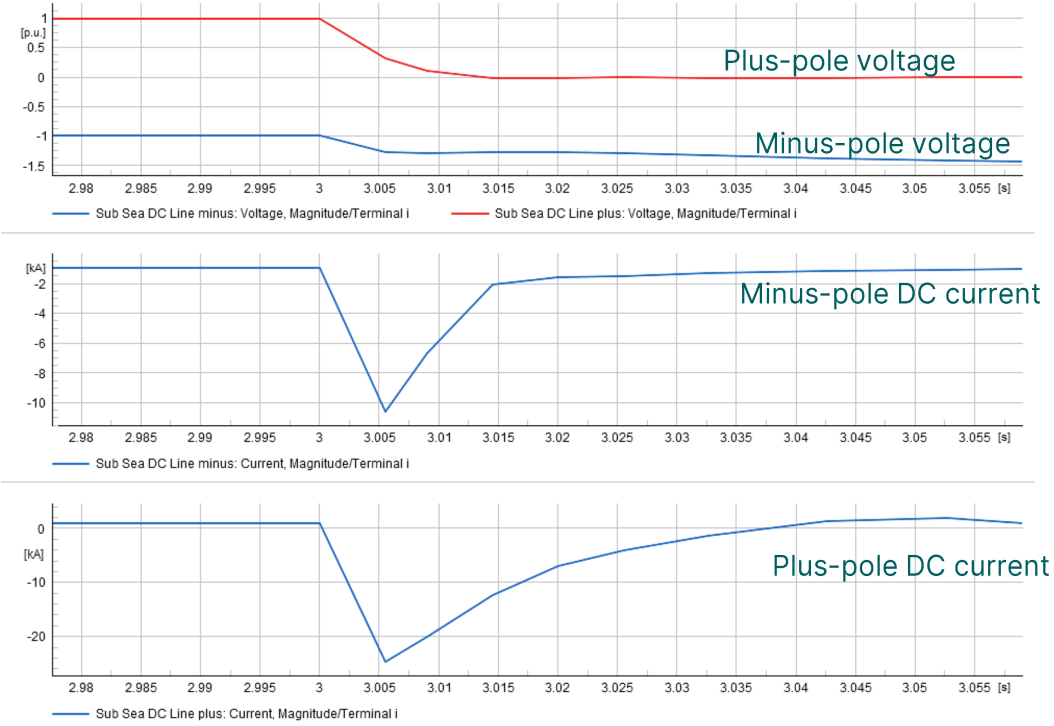
Block converter (Valves are protected (e.g. by bypass thyristors))

Trip ACCB

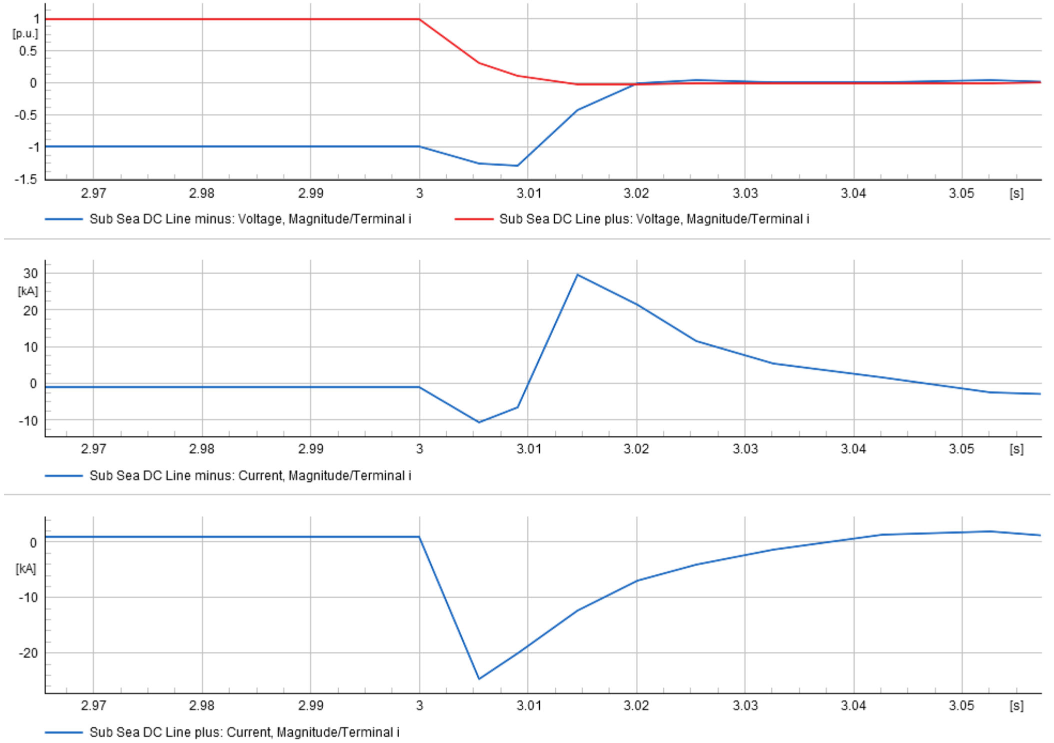
DC faults clearing – point-to-point system

Valves are protected (e.g. by bypass thyristors)

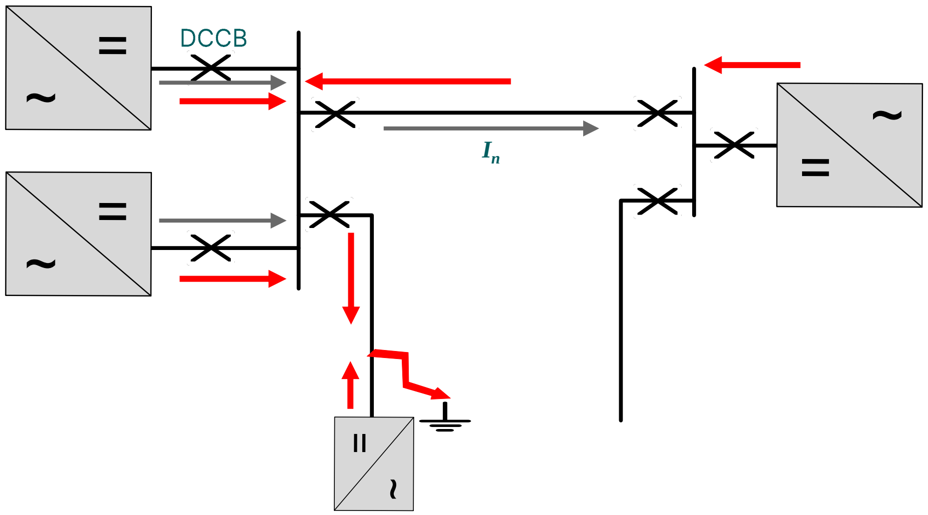
Fault 1: plus-pole to ground @ 3s



Fault 2: fault 1 @3s + minus-pole to ground @ 3.01s



HVDC grids - new requirements



- With AC protection, a single DC fault trips the whole grid
- DCCB options:
  - Assuming DCCB everywhere
    - Discrimination – how to identify and isolate faulted section only
    - Breakers of different class/ different settings (line side/converter side)
  - Breakers at selected locations
    - Allow system split during faults

DC protection approach to HVDC grids

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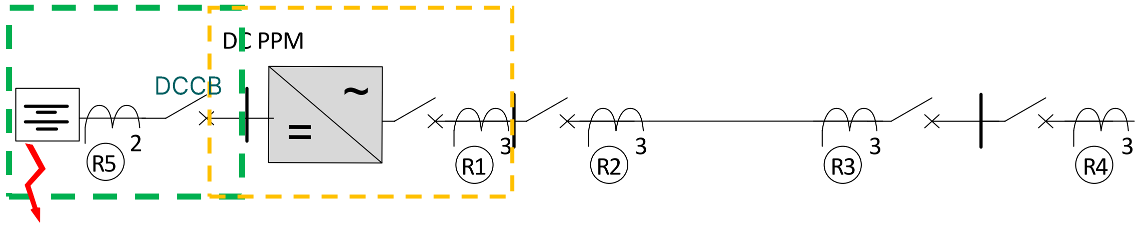


Detect the fault

At each DCCB

→ Trip all DCCB that detected fault

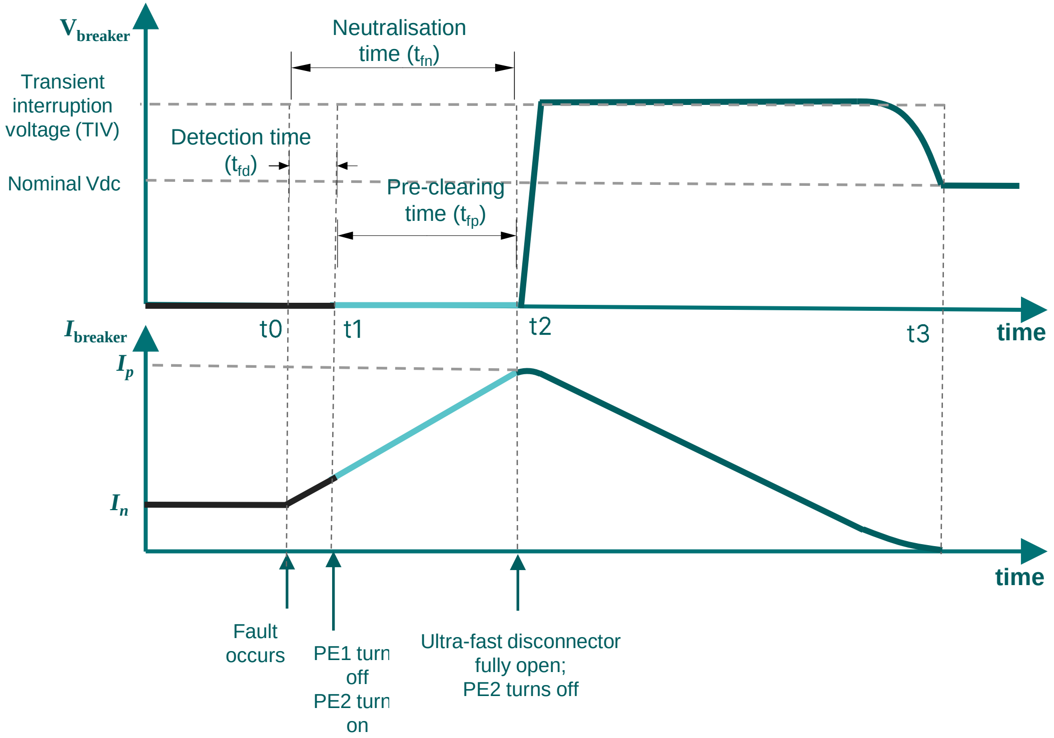
→ Identify and isolate the faulted section

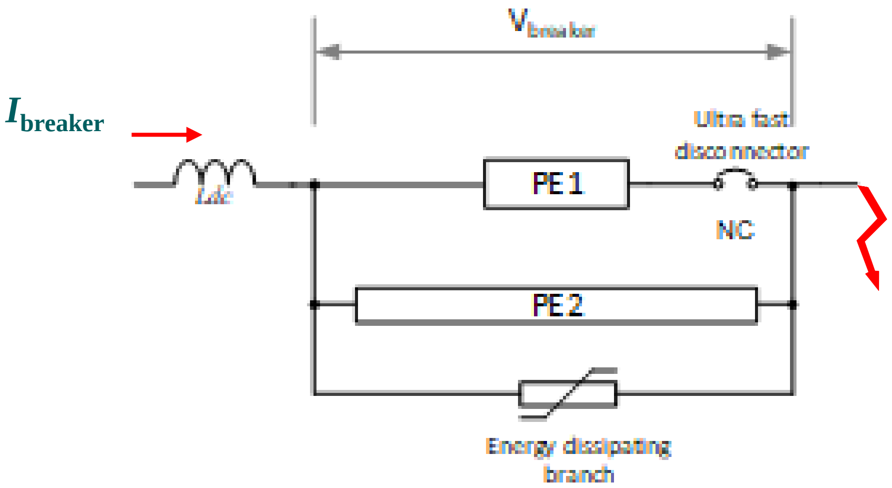
→ Reclose DCCB with no faulted section

Block the converters that detect OC (*optional*)

Deblock the converters at healthy sections

DCCB – operating principle





Hybrid DCCB

PE1 : main power electronics branch

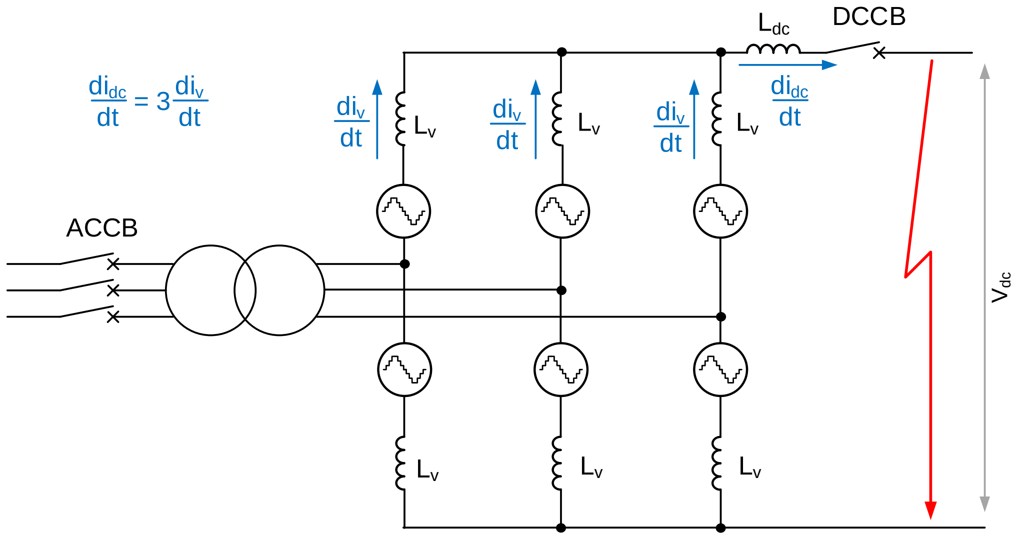
PE2 : Current Commutation branch

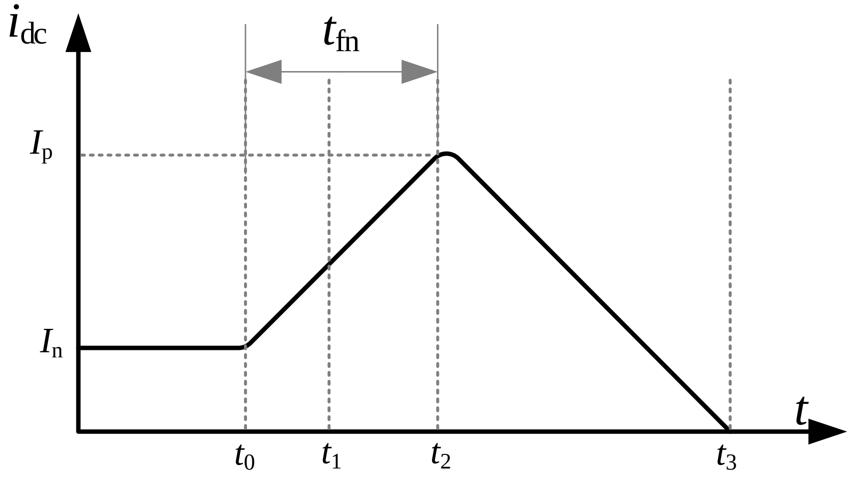
DCCB – operating principle

Current interruption requirement (I_p) for the DCCB depends strongly on the neutralisation time (t_{fn}) and inductance in the current fault path

Peak DCCB interruption current

$$I_p = I_n + \frac{di_{dc}}{dt} \cdot t_{fn}$$





Initial di/dt in DCCB

$$\frac{di_{dc}}{dt} = \frac{V_{dc}}{L_{eff}}$$

$$L_{eff} = \left[\frac{2 \cdot L_v}{3} + L_{dc}\right]$$

DCCB design metrics

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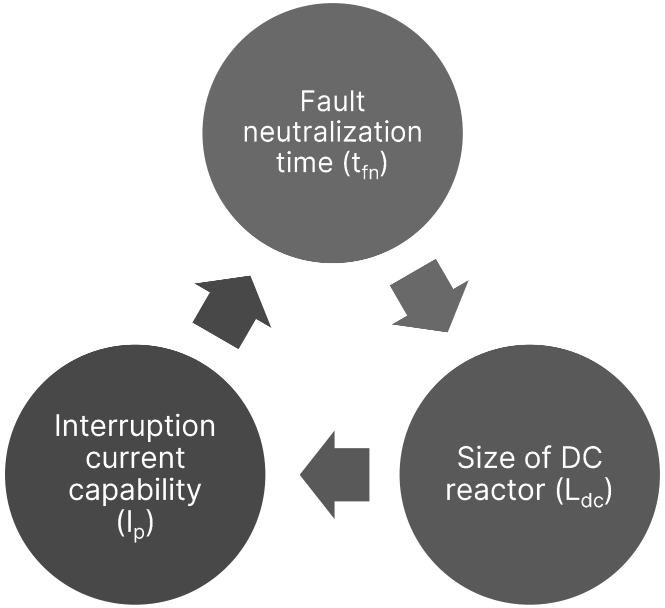
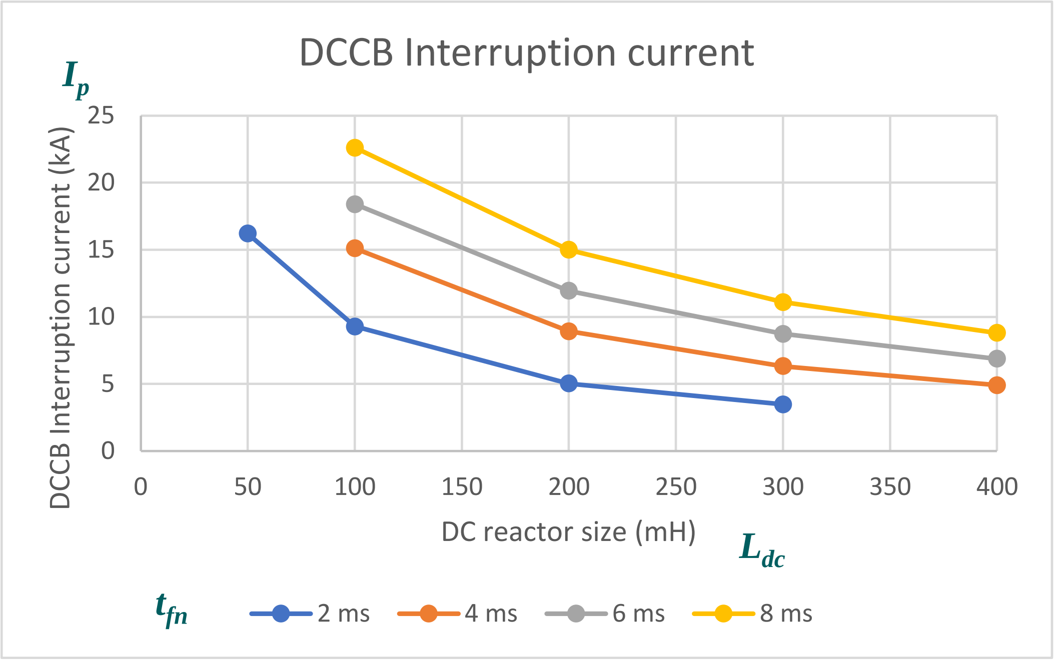
Three inter-dependent variables
(for same I_n, V_{dc}, $L_{circuit}$)



$$I_p = I_n + \frac{V_{dc}}{L_{dc}+Lc_{ircuit}} \cdot t_{fn}$$

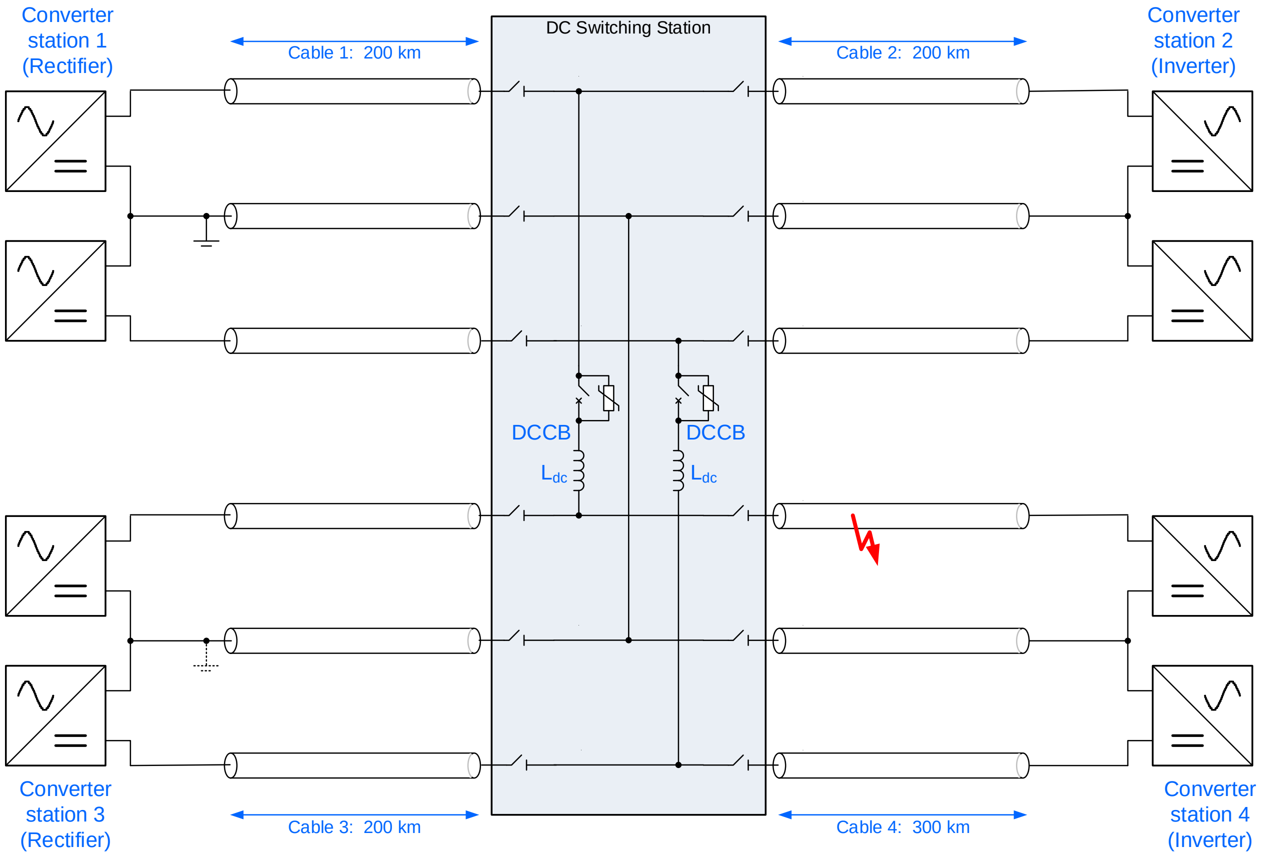


I_n depends on the location of the breaker

$L_{circuit}$ is the dependent on the fault location

DCCB design – impact of breaker location

Expansion of two independent bipoles using an intermediate DC Switching Station

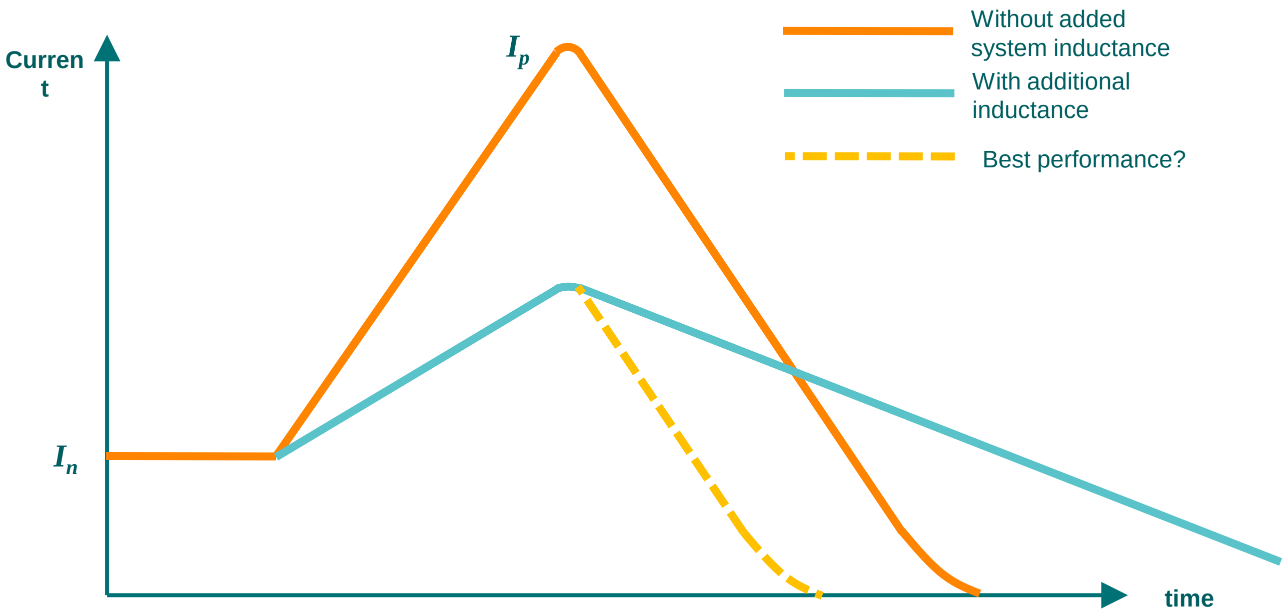


- Lower I_p due to lower I_n
- Cost-effective way of adding flexibility
- But DCCB is needed to prevent losing both bipoles for one fault.
- Only one DCCB and one DC reactor needed (per pole)
- Very simple protection strategy:
  - OC in DCCB → open DCCB
- N-1 fault → AC protection approach

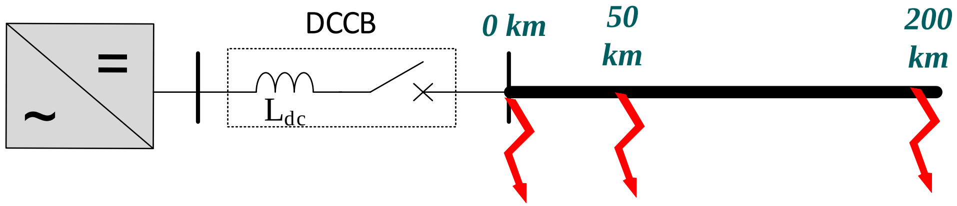
DCCB design – impact of inductance

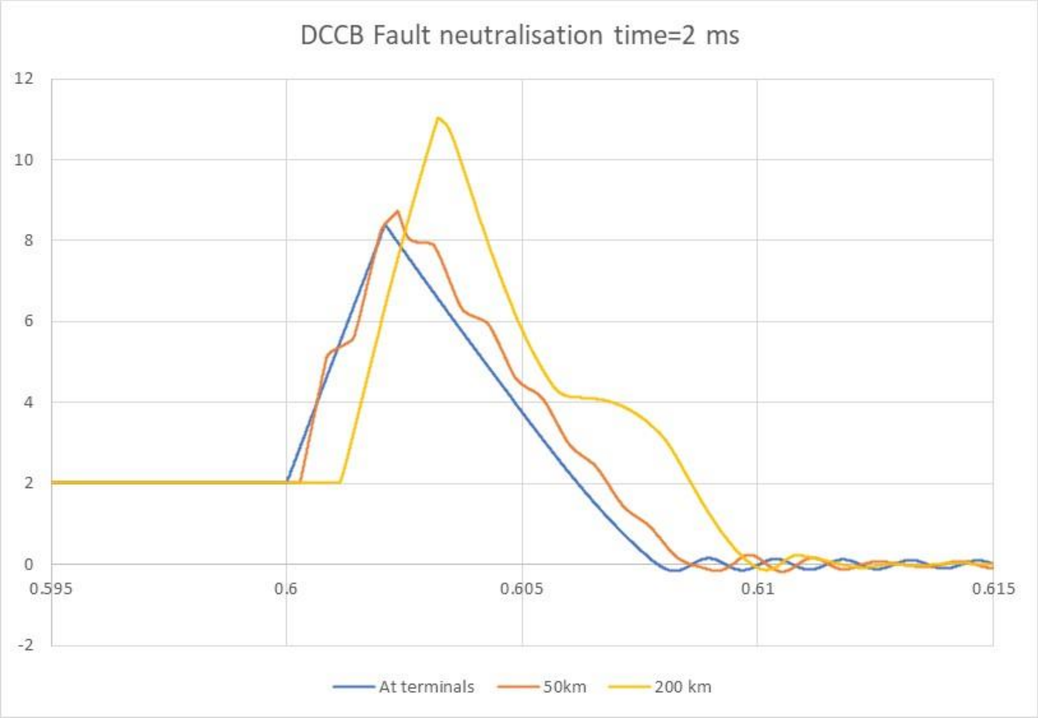
Higher inductance:

- Lower Ip
- But slower current decay rate



DCCB design – impact of fault location





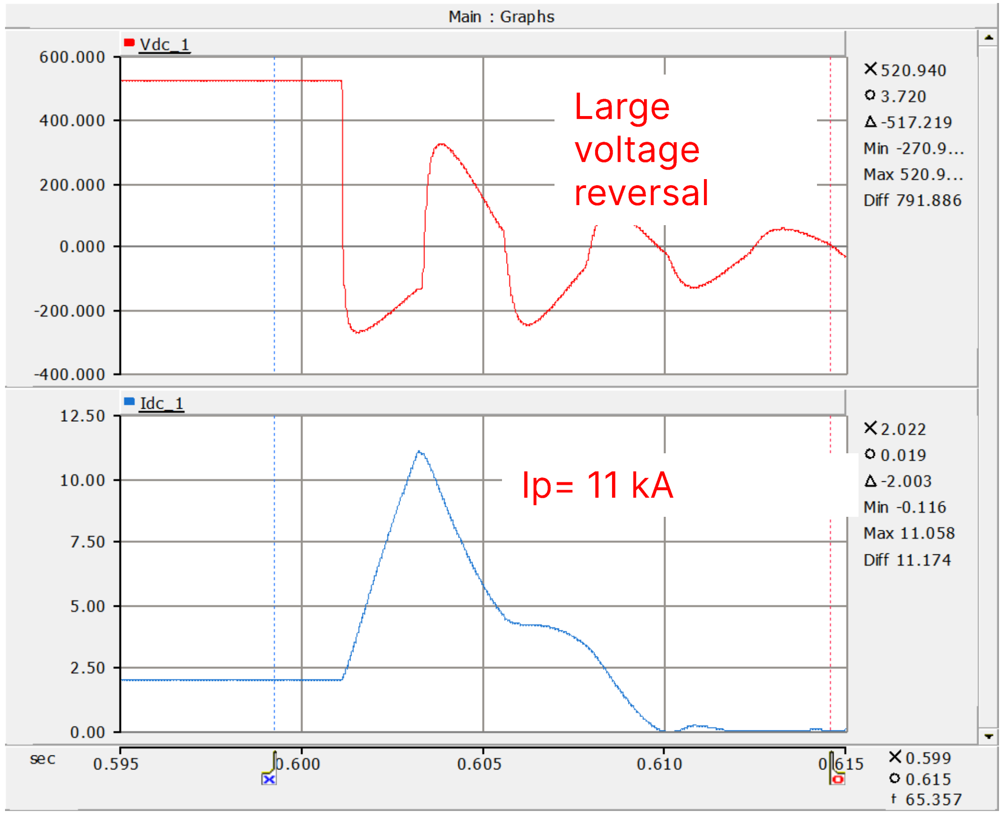
$L_{dc} = L_v = 100$ mH. Expected initial di/dt = 3.14 kA/ms

- Fault directly at converter station gives the expected response
  - Ip = 8.3 kA
- Faults at a distance from converter station give more complex results
  - Reason: Reflection at cable/converter station boundary causes partial voltage reversal

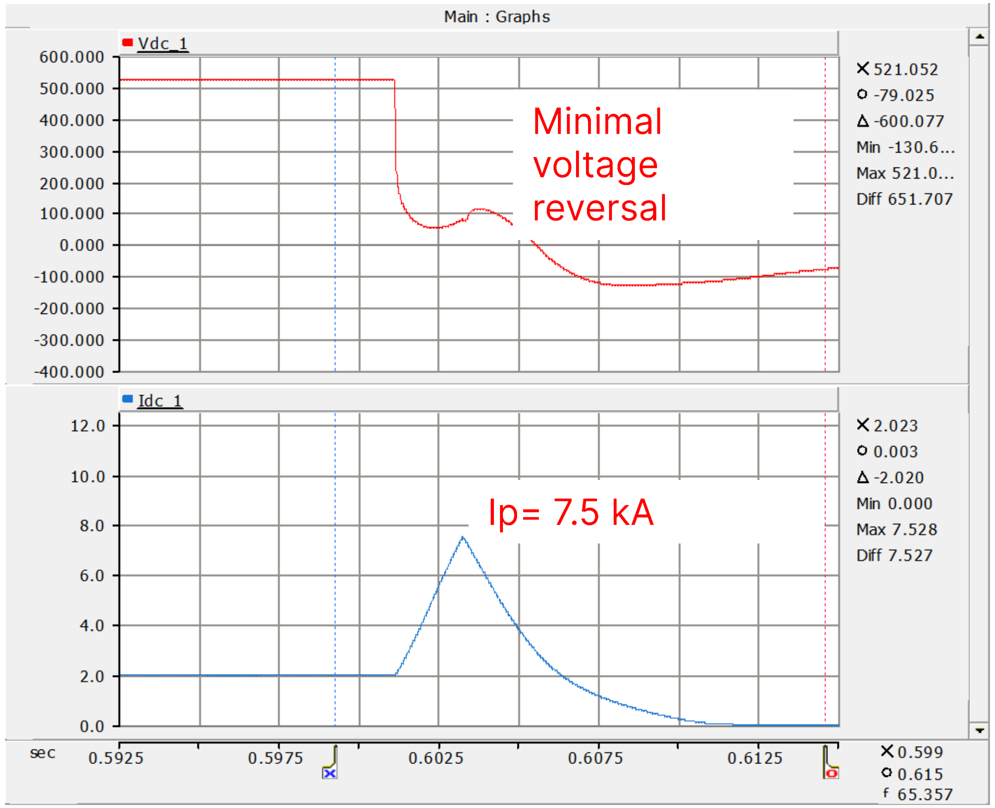
DCCB design – impact of cable type

Point-to-point case, Ifn = 2 ms

ρ_{sheath} = 2.6 x 10^{-8} Ω.m (Aluminium)



ρ_{sheath} = 2.2 x 10^{-7} Ω.m (lead)



Simulations showed little influence from: Soil resistivity, Location of sheath earthing, Resistance of sheath earthing - BUT sheath resistivity has a very big effect

DCCB design – impact of remote converters mode of operation

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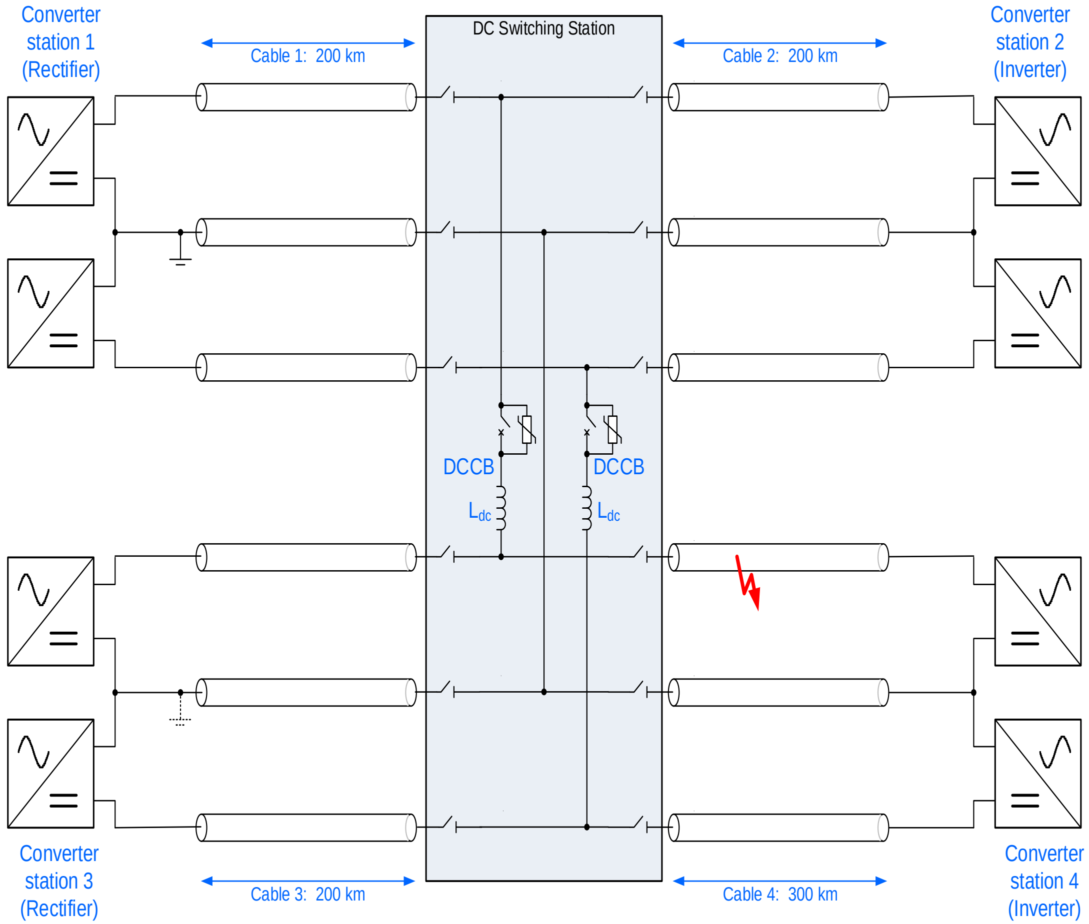
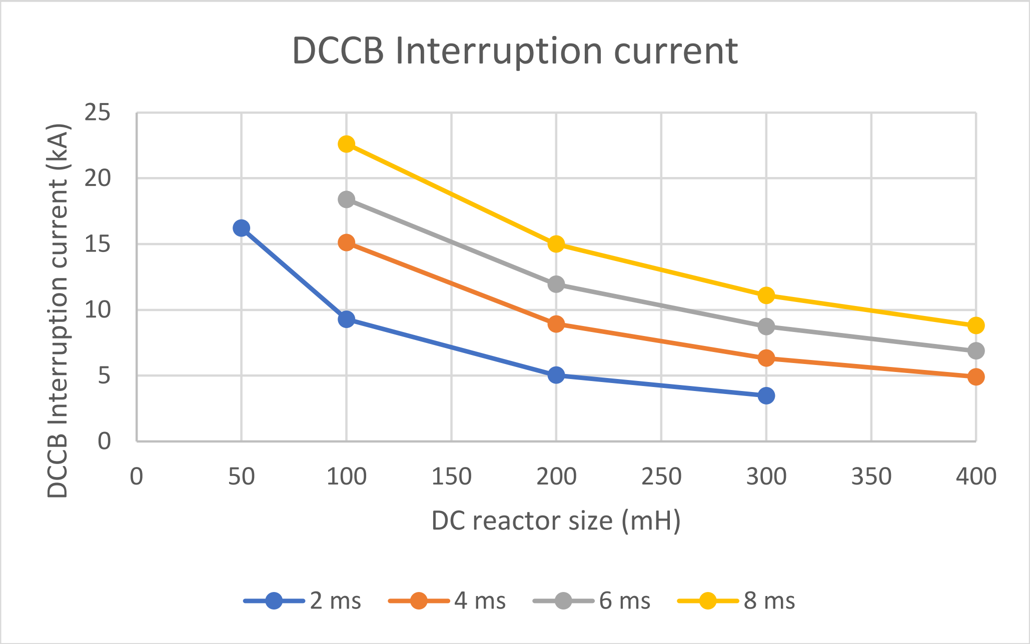
Two main options for converters 1 and 2 (healthy converters)

- Remote converters remain deblocked
  - Valve currents must remain within the SOA for the IGBTs.
    - DC reactor must be increased until this condition becomes true.
  - Typical manufacturer recommendation is:
    - SOA < 2 x rated current
  - This corresponds to 4 x rated DC current,
    - i.e. DC bus current of 8 kA
- Remote converter temporarily blocks during fault clearing
  - System will experience a loss of power for a short period of time
- Impact on Fault ride through requirements and performance

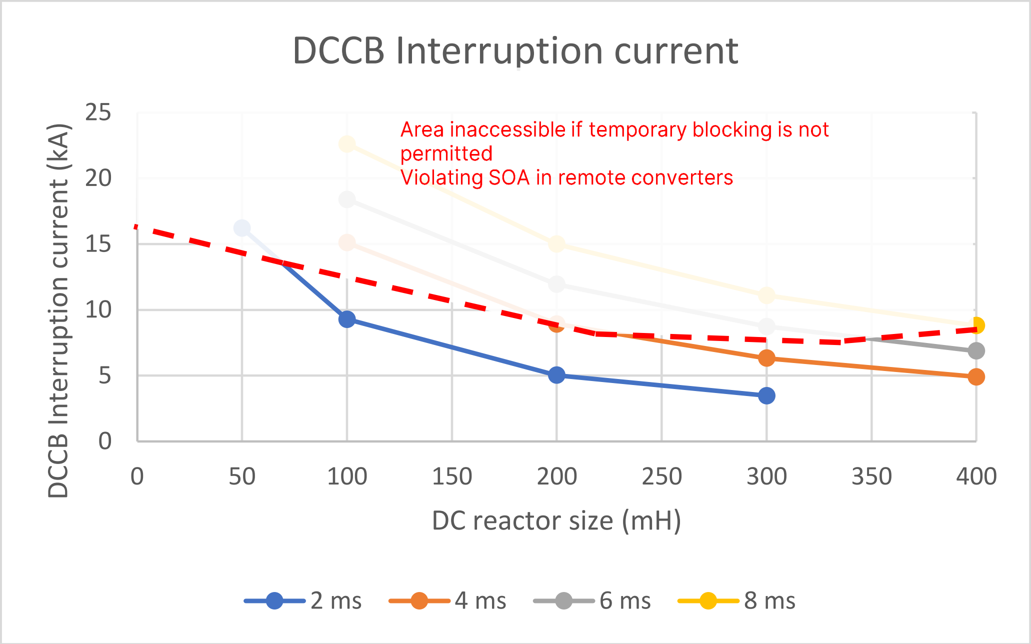


DCCB design – Impact of remote converters mode of operation

Converters block during the fault



Converters are deblocked during the fault



Conclusions

- DC grids are emerging due to the requirements for cost effective solutions for deep electrification esp. offshore.
- Subsystems designs have been carried out during the last decade
  - EC Twenties project concluded in 2013 - GE prototype of a hybrid DCCB
- Regardless of the breaker technology, the design metrics (mainly three) are interdependent
  - – Current interruption capability
  - – Fault neutralization time
  - – Breaker inductance
  - They are impacted by:
  - – Breaker location in the DC Grid
  - – Cable type
  - – Allowed mode of operation of converters during a DC fault (block/remain deblocked)
  - – Effective fault inductance
  - Different DC breaker classes might need to exist to cover the evolution of DC Grids