PROMOTioN
PROGRESS ON MESHED HVDC OFFSHORE TRANSMISSION NETWORKS

DC Grid Protection: Performance, interoperability, What is the TRL?

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Promotion Workshop on DC Circuit Breakers and DC Grid Protection – Brussels 27/09/2019

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DC grid protection is different from AC grid protection

Different fault current phenomena compared with AC systems

Different constraints compared with AC systems

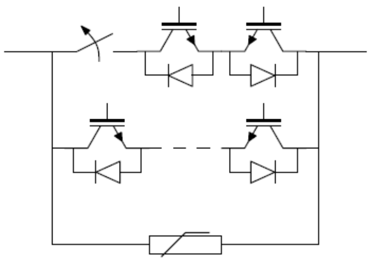
- Sensitive power electronic components
- Faster controls

Different economics compared with AC systems

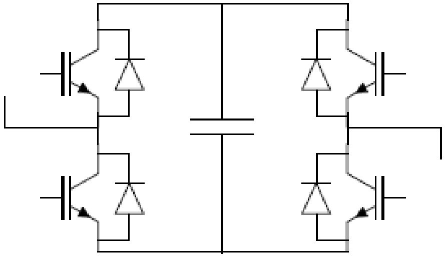
- Footprint and cost of DC circuit breakers

DC grid protection may be implemented in various ways, which fit different purposes but leads to different performance

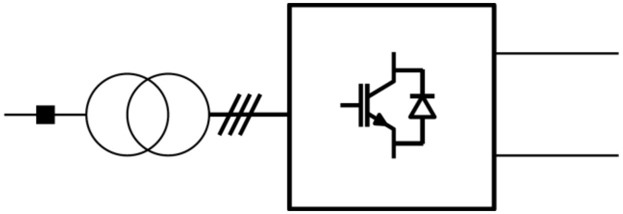
Different equipment for fault clearing may be used



DC circuit breakers



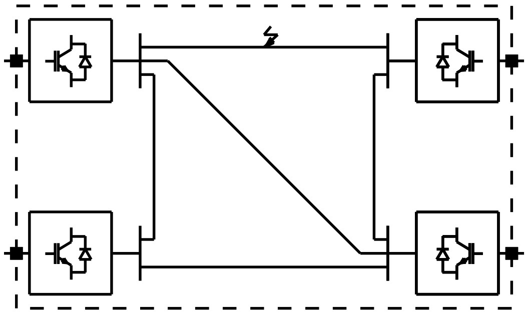
Fault-blocking converters



Converter ac breakers

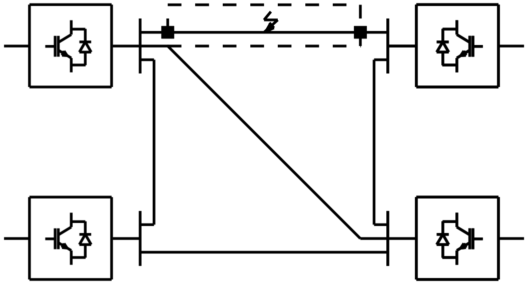
Using superconducting fault current limiters and mechanical DC circuit breakers

Fault clearing strategies were classified under different philosophies



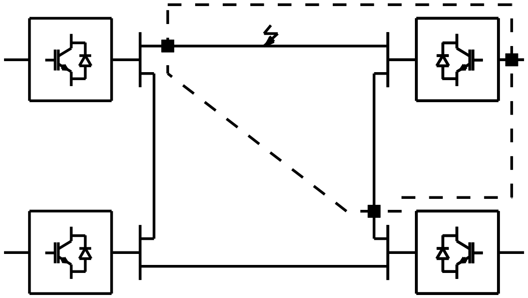
Non-selective

- De-energize the entire grid
- Switch off the faulted line
- Energize the grid and resume power flow



Fully selective

- Protect every line and node individually



Partially selective

- Allow larger sections of the grid to be disconnected in case of a fault

Fault clearing strategies can be developed based on the technology and philosophy used

Fully selective

- Using power electronic/hybrid/mechanical DC circuit breakers
- Using DC circuit breakers and superconducting fault current limiters

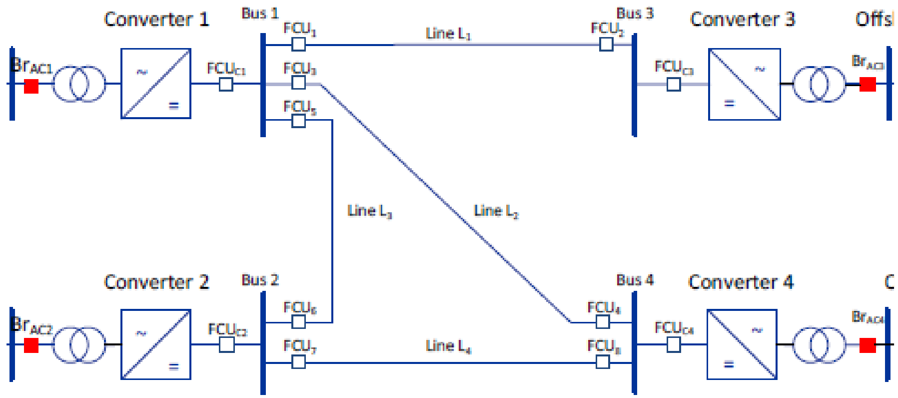
Non-selective

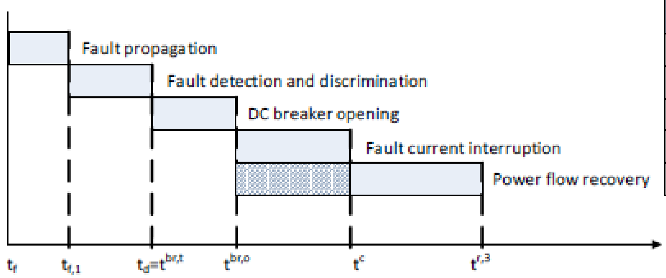
- Using AC circuit breakers
- Using converters with fault blocking capability (e.g., full-bridge)
- Using DC circuit breakers at the converter terminals
- Open Grid

Partially Selective

- Several combinations possible
  - Split the grid using DC circuit breakers or DC/DC converters
  - Using any of the options of non-selective to clear the fault in the de-energized subgrid

Several parameters were used to characterize fault clearing strategies (Promotion D4.2)





Interval	Duration
t_f-$t_{f,1}$	us to ms
$t_{f,1}$-t_d	us to ms
t_d-$t^{br,o}$	0.5-20 ms
$t^{br,o}$-t^c	few ms
$t^{br,o}$-$t^{r,3}$	tens of ms

Protection zone		C1	C2	C3	C4	Protection equipment in operation
1	$F_{L1,ptg}$	CO	CO	PS	CO	Br_1, Br_2
2	$F_{L2,ptg}$	CO	CO	CO	CO	Br_3, Br_4
3	$F_{L3,ptg}$	CO	CO	CO	CO	Br_5, Br_6
4	$F_{L4,ptg}$	CO	CO	CO	CO	Br_7, Br_8

Key components

Technical layout

Primary fault clearing sequence

Backup fault clearing sequence

Protection matrix

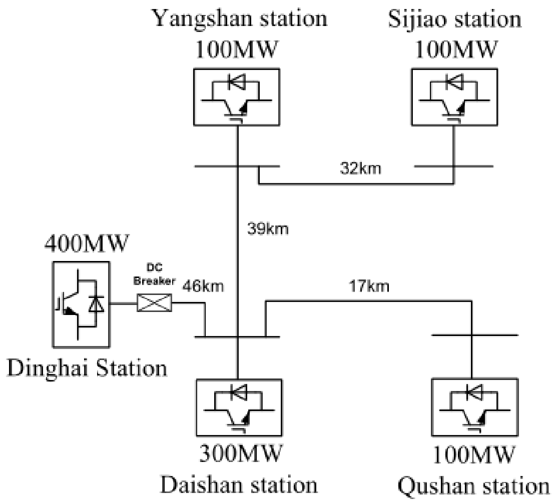
Key Performance Indicators (Promotion D4.3)

- Efficiency indicators
  - Fault clearance time
  - DC voltage restoration time
  - Active Power Restoration time
  - Reactive Power restoration time
  - Transient energy imbalance
- Failure indicators (reliability)
  - Primary sequence failure
  - Protection strategy failure
- Cost indicators

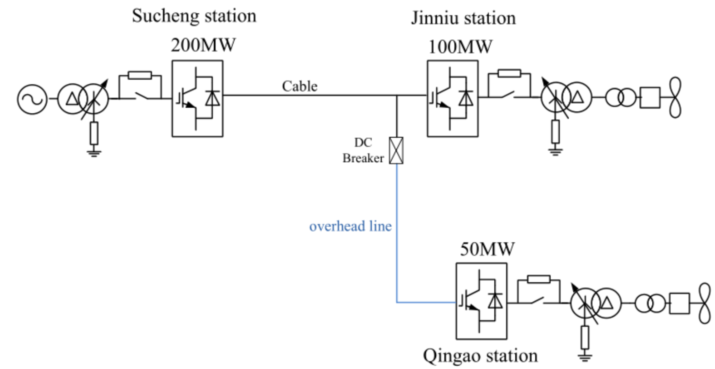
TRL of fault clearing strategies: surprisingly high

	PHILOSOPHY	MAIN INTERRUPTING COMPONENT	COMPONENTS READY?	REAL SYSTEM?	TRL	Systems/Demonstrators
1	Non-Selective	ACCB	Yes	Yes	High	Nan’ao (2013-2017) Zhoushan (2014-2016) MTTE Caithness-Moray
2	Non-Selective	DCCB	Yes	Yes*	High	Zhoushan (2016-now) **Promotion Demo**
3	Non-Selective	FB Converter	Yes (?)	No (Planned)	Medium	GE demonstrator ULTRANET **Promotion Demo**
4	Partially Selective	DCCB	Yes	Yes	High	Nan’ao (2017-now)
6	Fully Selective	DCCB	Yes (?)	No (Planned)	Medium	Zhangbei **Promotion Demo**
7	Non-Selective	DCCB	Yes (?)	No	Medium	**Promotion Demo**
8	Non-Selective	SFCL	?	No	Low (?)	
9	Partially Selective	DCDC	?	No	Low	

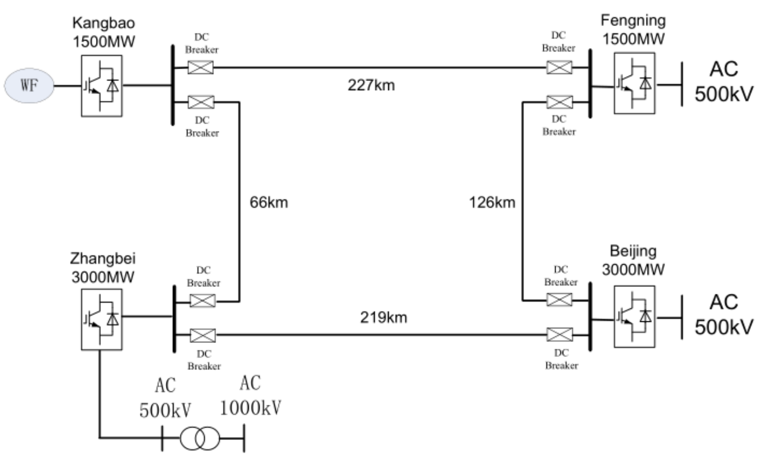
HVDC Grid Protection in Real Projects



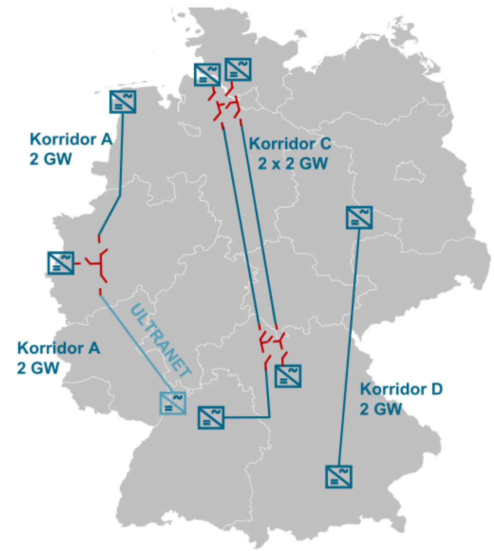
Zhoushan – NS Hybrid DCCB



Nan’ao – PS Mechanical DCCB



Zhangbei – FS Hybrid DCCB



ULTRANET – NS FB

Sources: D. Jovcic, G. Tang and H. Pang, "Adopting Circuit Breakers for High-Voltage dc Networks: Appropriating the Vast Advantages of dc Transmission Grids," in *IEEE Power and Energy Magazine*, vol. 17, no. 3, pp. 82-93, May-June 2019. - Siemens

Interoperability

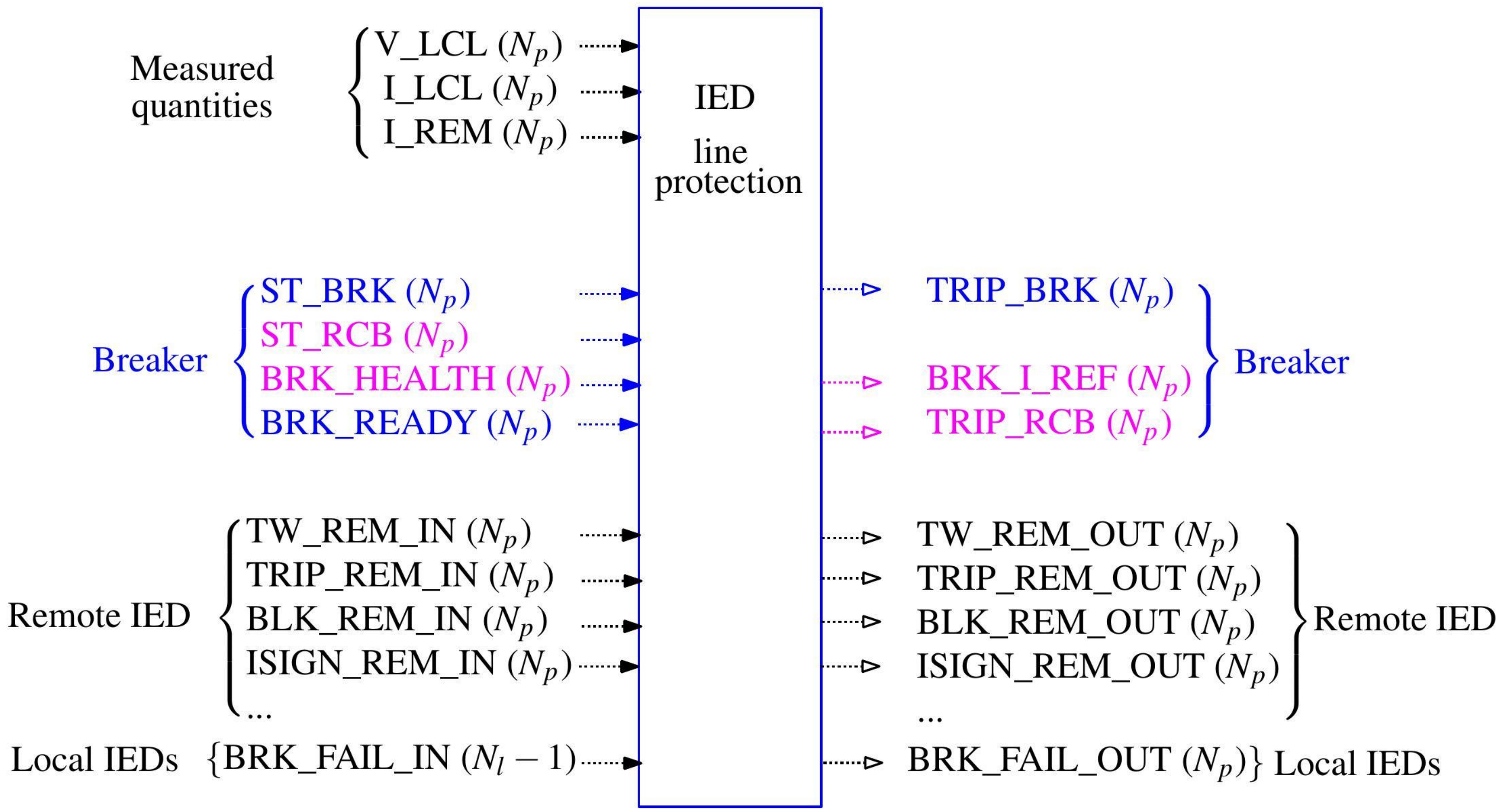
- Fault-ride through of HVDC converters determines design of DC circuit breakers
  - Is a converter allowed to temporarily block or not?
- In case a converter needs to respond to a DC fault (e.g. temporary blocking), should there be any interaction between the DC IEDs and the ACDC converters
- DC IEDs should be able to interact with DC circuit breakers
  - Many flavors of circuit breakers; do we need standardized interfaces?

Interoperability Example – IED - DC Circuit Breakers

- **Minimally required functions:**
  - Open/close on a tripping/closing order
  - Repeated O-C-O operation
  - Communicating breaker status: open/close, ready/not-ready
- **Auxiliary functions:**
  - Proactive opening
  - FCL operation during a fault/restoring DC voltage
  - Fast closing/opening
  - Self protection
  - Breaker failure internal detection and communicating the healthy/not-healthy to the IED

Source: M. Wang et al, Pre-standardisation of Interfaces between DC Circuit Breaker and Intelligent Electronic Device to Enable Multivendor Interoperability, in Proc. CIGRE Aalborg, Aalborg, Denmark, 4-7 June 2019

Proposed IED Interface



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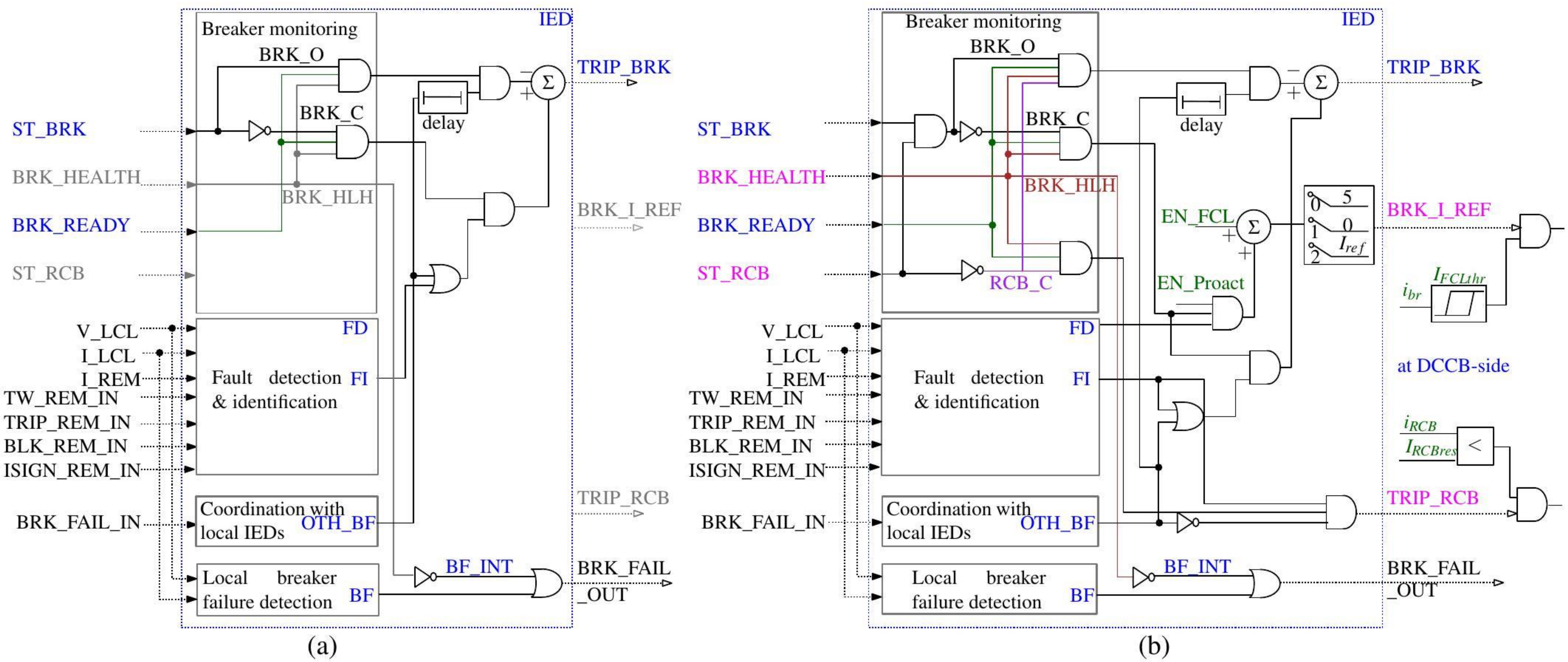

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Main conclusions

- TRL level of DC grid protection surprisingly high thanks to fast advances in China
  - Although Europe is catching up fast through demos and planned systems
- Almost all protection strategies are being implemented, from non-selective over partially selective to fully selective
- Biggest challenge for DC grid protection may lie in achieving multivendor interoperability
  - As current implementations are (essentially) single-vendor

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APPENDIX

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