



PROMOTiON

PROGRESS ON MESHED HVDC
OFFSHORE TRANSMISSION
NETWORKS



DC grid protection

Promotion WP4 outcomes

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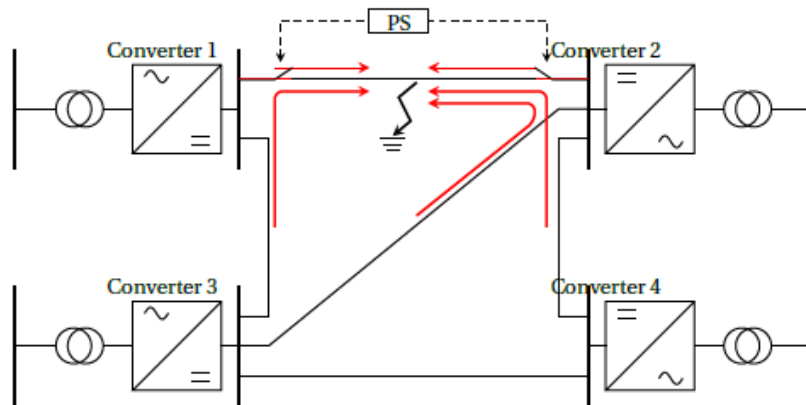
Contents

- Why DC grid protection research
- Protection: fault detection & clearing → protection strategy
- Towards risk based development of DC protection systems
- Early results
- The IED

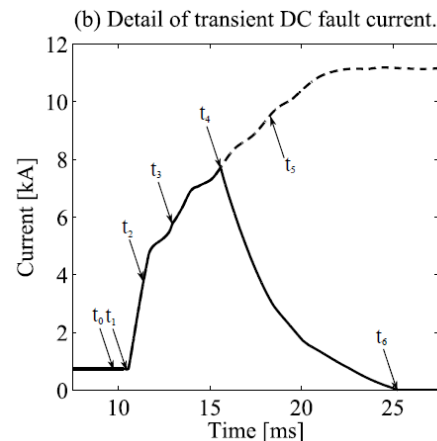
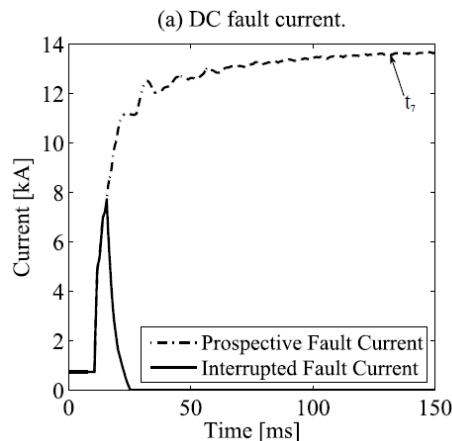


Fault currents within a DC grid

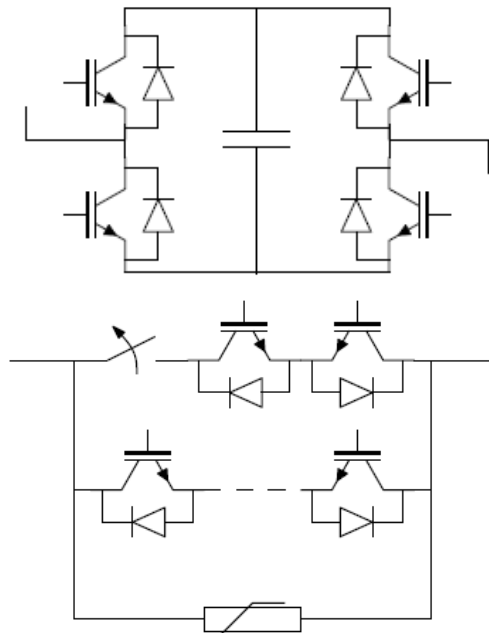
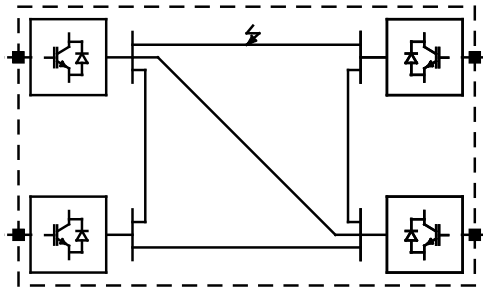
Example pole-to-pole fault



- Fault current:
 - No zero crossings
 - High rate-of-rise
 - High steady state value
 - Sensitive (expensive) converters

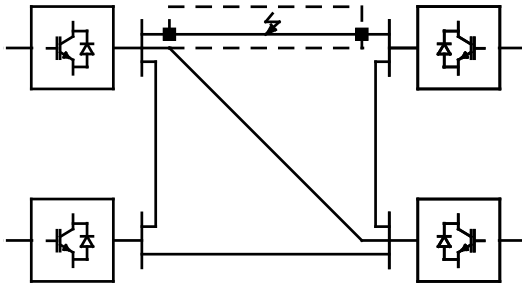


Different technologies exist to interrupt a DC fault current

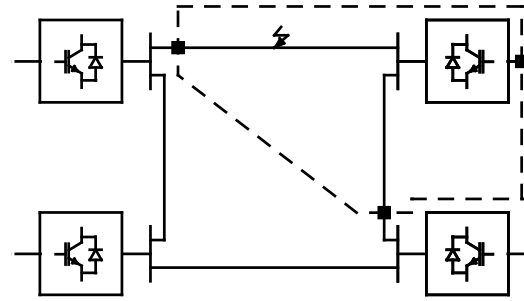


- Converter AC breakers
 - As used in existing projects
 - Slow (40-60 ms opening time)
 - Not selective
- Fault-current blocking converters
 - Higher losses compared to half-bridge
 - Fast (responsive within a few ms)
 - Not selective
- DC circuit breakers
 - Operating time of 2-10 ms
 - Trade-off in losses vs speed
 - Allows selective fault clearing

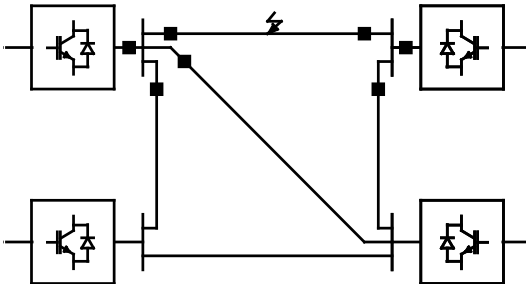
The use of different technologies leads to various fault clearing strategies



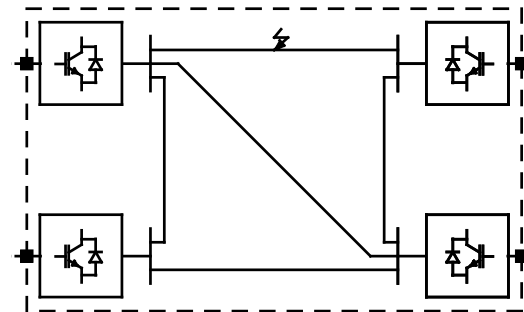
Selective: using
DC breakers in every line



Partially selective: split
DC grid in sub-grids



Open Grid:
alternative breaker
sequence



Non-selective: shut
down the whole DC
grid

Small – Medium – Large (impact)

- **“Small impact” grid:** the loss of the whole HVDC grid will only have limited impact on the AC grids, seen as small voltage and frequency variations which are quickly restored. Loss of the system has the same impact as an “N-1” event.
- **“Medium impact” grid:** the loss of the whole HVDC grid will cause significant voltage, rotor angle and frequency transients seen on the AC grid; AC grids are able to recover from the contingency, without black-out, but possible load shedding in part of the system.
- **“Large impact” grid:** The DC grid forms the backbone of the transmission system and loss of this system likely leads to a blackout.

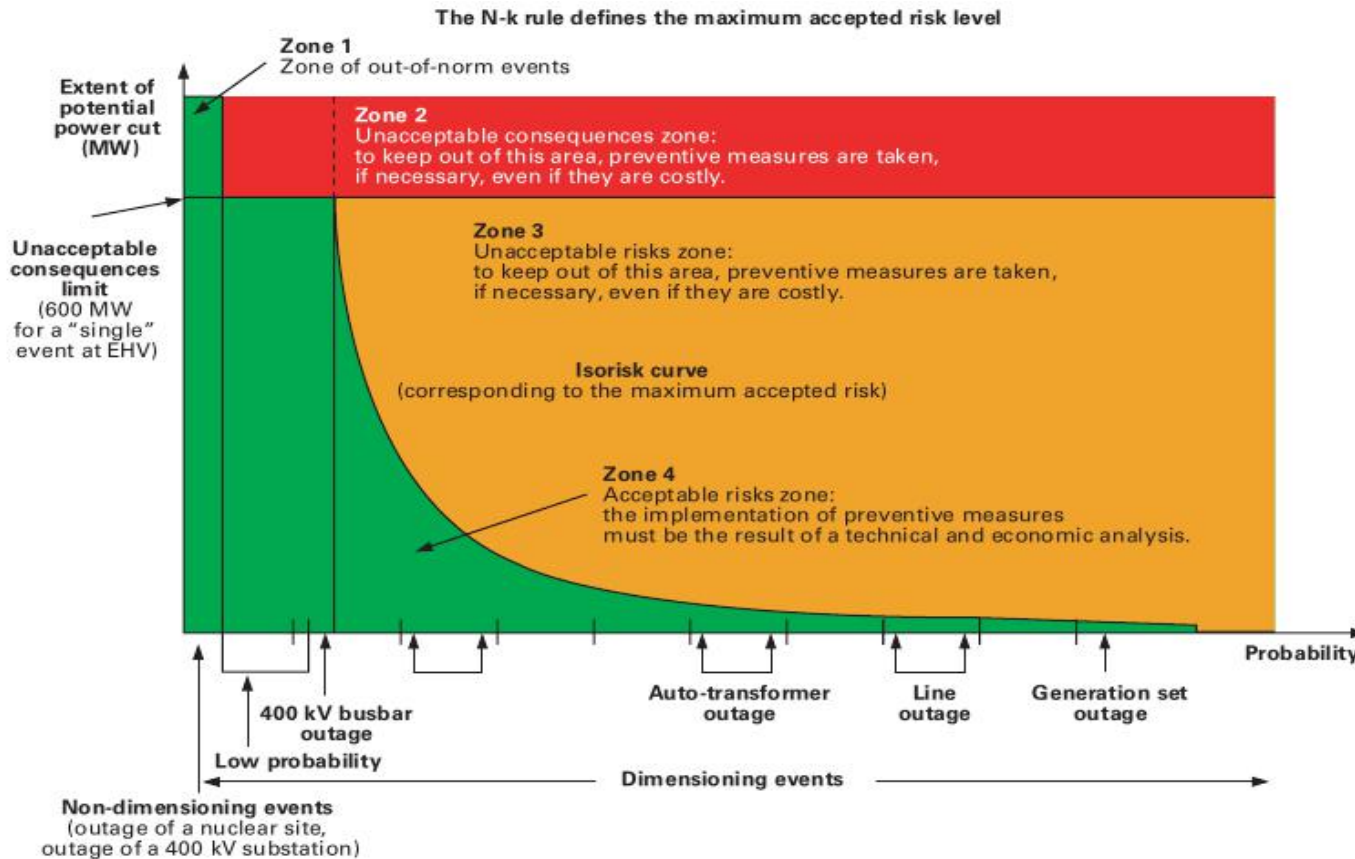


Protection matrix approach determines converter response for each type of fault (based on CENELEC TC8X WG6)

Fault separation concepts	Typical separation times	Behaviour of the DC grid System or parts thereof
Continued operation	< few ms	Only the protection zone having the fault gets discharged, power flow in the other protection zones is maintained, probably with some adjustments to accommodate for the new grid topology without the faulty part.
Temporary stop	< 200 ms	The power flow in the entire DC grid System or a zone thereof is temporarily affected. The affected converters or DC circuit breakers control the fault current to zero or break it. After separating the faulty part of the protection zone, the remaining DC grid System is recharged and power flow recovers.
Permanent stop	> 200 ms	The regarding protection zone will shut down. It can be restarted manually or automatically.

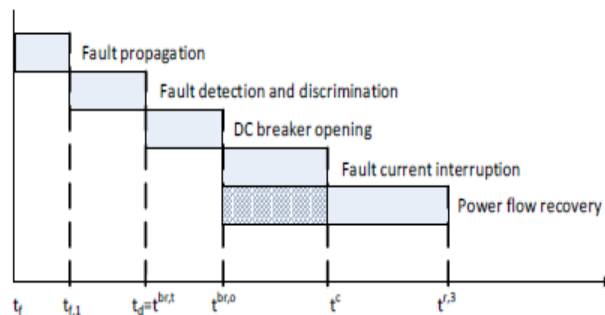
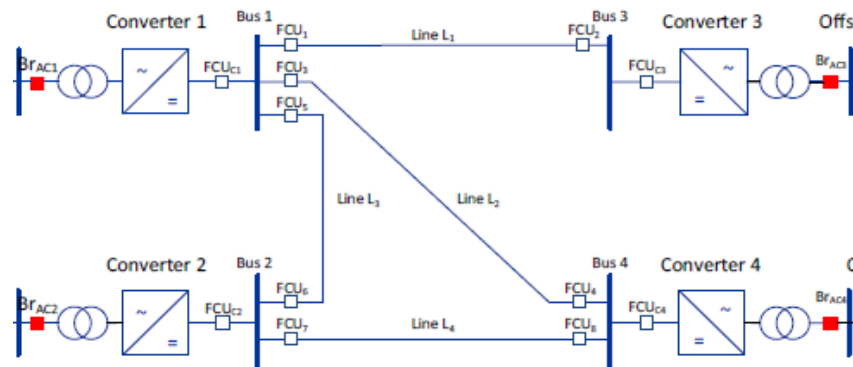


Relevant fault causes → consequences and probability → risk



(source: RTE memento on electrical system security now on-line).

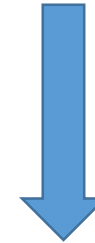
Detailed analysis on different parameters to characterize fault clearing strategies



Interval	Duration
$t_f - t_{f,1}$	us to ms
$t_{f,1} - t_d$	us to ms
$t_d - t_{br,0}$	0.5-20 ms
$t_{br,0} - t^c$	few ms
$t_{br,0} - t^{r,3}$	tens of ms

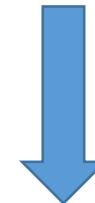
Key components

Technical layout



Primary fault clearing sequence

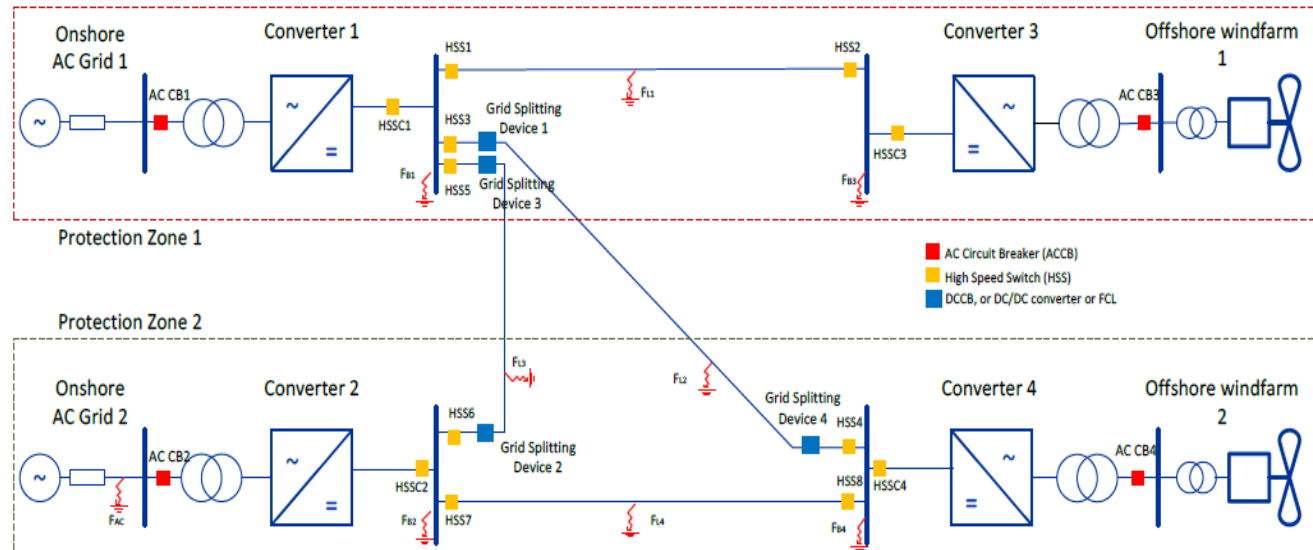
Backup fault clearing sequence



Protection matrix

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

Example protection matrix for partially selective strategy



Protection zone		C1	C2	C3	C4	Protection equipment in operation
1	$F_{L1.ptq}$	PS	CO	PS	CO	DCCB ₁ , DCCB ₃ , ACCB ₁ , ACCB ₃
1-2	$F_{L2.ptq}$	CO	CO	CO	CO	DCCB ₁ , DCCB ₄
1-2	$F_{L3.ptq}$	CO	CO	CO	CO	DCCB ₂ , DCCB ₃
2	$F_{L4.ptq}$	CO	PS	CO	PS	DCCB ₂ , DCCB ₄ , ACCB ₃ , ACCB ₄
	$F_{L1.ptp}$	PS	CO	PS	CO	DCCB ₁ , DCCB ₃ , ACCB ₁ , ACCB ₃
	$F_{L2.ptp}$	CO	CO	CO	CO	DCCB ₁ , DCCB ₄
	$F_{L3.ptp}$	CO	CO	CO	CO	DCCB ₂ , DCCB ₃
	$F_{L4.ptp}$	CO	PS	CO	PS	DCCB ₂ , DCCB ₄ , ACCB ₃ , ACCB ₄
1	$F_{B1.ptq}$	PS	CO	PS	CO	DCCB ₁ , DCCB ₃ , ACCB ₁ , ACCB ₃
2	$F_{B2.ptq}$	CO	PS	CO	PS	DCCB ₂ , DCCB ₄ , ACCB ₂ , ACCB ₄
2	$F_{B4.ptq}$	CO	PS	CO	PS	DCCB ₂ , DCCB ₄ , ACCB ₂ , ACCB ₄
	$F_{B1.ptp}$	PS	CO	PS	CO	DCCB ₁ , DCCB ₃ , ACCB ₁ , ACCB ₃
	$F_{B2.ptp}$	CO	PS	CO	PS	DCCB ₂ , DCCB ₄ , ACCB ₂ , ACCB ₄
	$F_{B4.ptp}$	CO	PS	CO	PS	DCCB ₂ , DCCB ₄ , ACCB ₂ , ACCB ₄

Faults which the protection system is expected to protect against

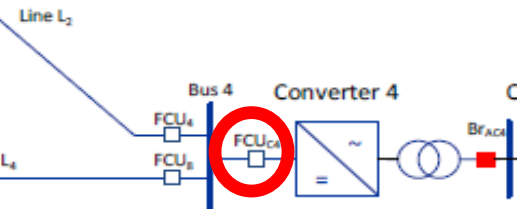
Other faults

conclusions: overview table

	STRATEGY ABBR.	PHILOSOPHY	MAIN COST DRIVER	FEASIBILITY				
				Low impact grid	Med. impact grid	High impact grid	Symm. Mon.	Bip.
1	FS DCCB Option 1	Fully Selective	DCCB	✓	✓	✓	✓	✓
2	FS DCCB Option 2	Fully Selective	DCCB and Converters	✓	✓	✓	✓ ¹⁰	✓
3	FS DCCB Option 3	Fully Selective	DCCB	✓	✓	✓	✓ ¹⁰	✓
4	FS SFCL	Fully Selective	SFCL	✓	✓	✓	? ¹¹	✓
5	NS ACCB	Non-Selective	/	✓	x	x	✓	✓
6	NS FB	Non-Selective	FB	✓	✓	x	✓	✓
7	NS DCCB	Non-Selective	DCCB	✓	✓	x	? ¹¹	✓
8	NS SFCL	Non-Selective	SFCL	✓	✓	x	? ¹¹	✓
10	Open Grid	Non-Selective	DCCB	✓	✓	x	? ¹¹	✓
11	ParS PS	Partially Selective	DCCB/DCD C	✓	✓	✓	✓	✓
12	ParS TS	Partially Selective	DCDC/DCC B/FB	✓	✓	✓	✓	✓

D4.2: broad comparison of fault clearing strategies for DC grids

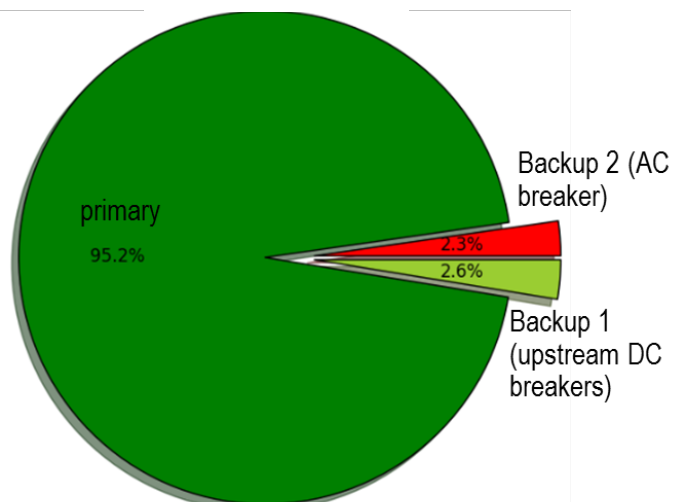




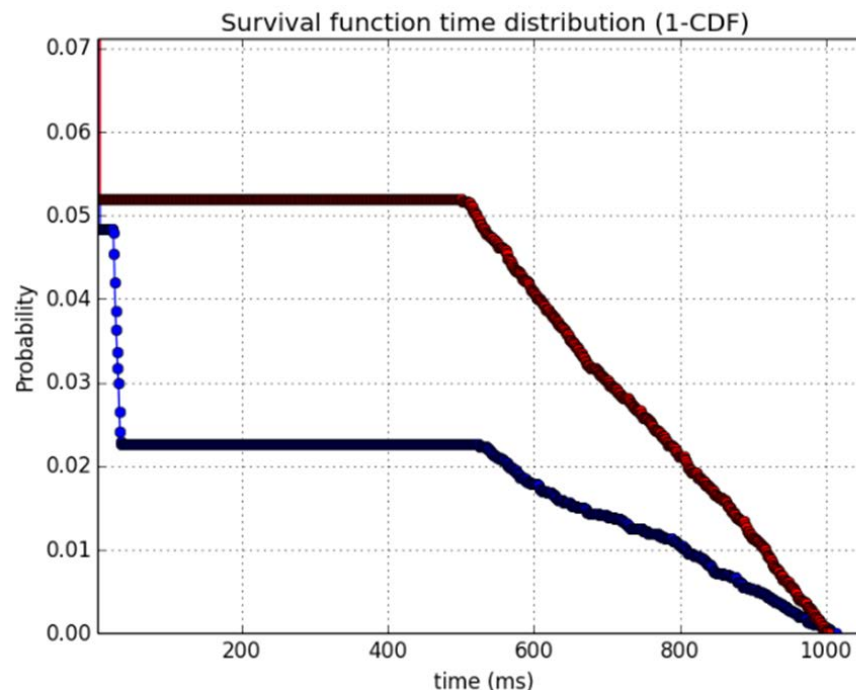
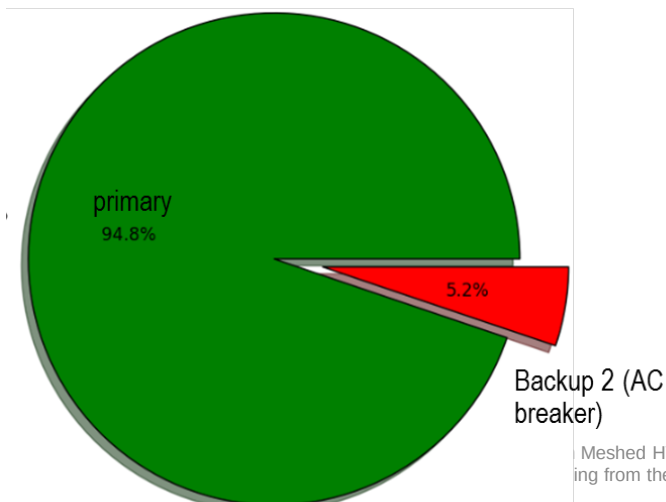
Next tasks: comparing costs and benefits of strategies

- Different strategies will lead to different possible end states
- Towards CBA
- Risk = **probability** X impact
- Example: benefit of DC busbar breaker (including backup)

with



without



HVDC IED developed and tested

- Zedboard
 - Sufficient computing power to have several algorithms in parallel
 - Multiple I/O capabilities
- Device has been developed
- Configurable
- Central or decentral configuration
- Communication protocol
 - Ethercat or HSR
- Developing tests:
 - Using similar types of tests as for AC relays
 - Fault detection
 - Selectivity
 - Noise sensitivity
 - ...
- Promotion KTH IED
- Mitsubishi IED



Conclusions

- DC grids require protection
 - Different philosophies using different technologies
- Risk-based evaluation as in AC systems necessary
- Continuation has the focus on:
 - Towards industrialized solutions
 - Interoperability
 - Failure modes
 - Performance evaluation
 - Continuing developing IED and adding new algorithms
 - Developing tests
 - Cost benefit analysis (deviations due to protection equipment)

APPENDIX

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