PROMOTioN
PROGRESS ON MESHED HVDC OFFSHORE TRANSMISSION NETWORKS

PROMOTioN WP 2 & 4: What impact does changing inertia have on offshore HVDC power system

Joint workshop Migrate – Promotion
February 28 2019, Berlin

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RWTH ● Christina Brantl

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

Connection between HVDC Offshore systems and inertia

Onshore System

- Replacement of conventional power plants by offshore windfarms (among others)
- HVDC connection of remote offshore windfarms
- Higher number of converters in the AC system
- Inertia in the AC grid is reducing
- The requirements on the converters to stay connected to the AC onshore grids might change

HVDC Offshore System

- Behaviour of DC systems under faults differs significantly from AC systems under faults
- Different system configurations, protection strategies and components are proposed and discussed for HVDC systems
- The impact on the AC system depends on the chosen system layout, technology and strategy
- The allowable deviations or outages at the PoC-AC will get stricter with lower inertia

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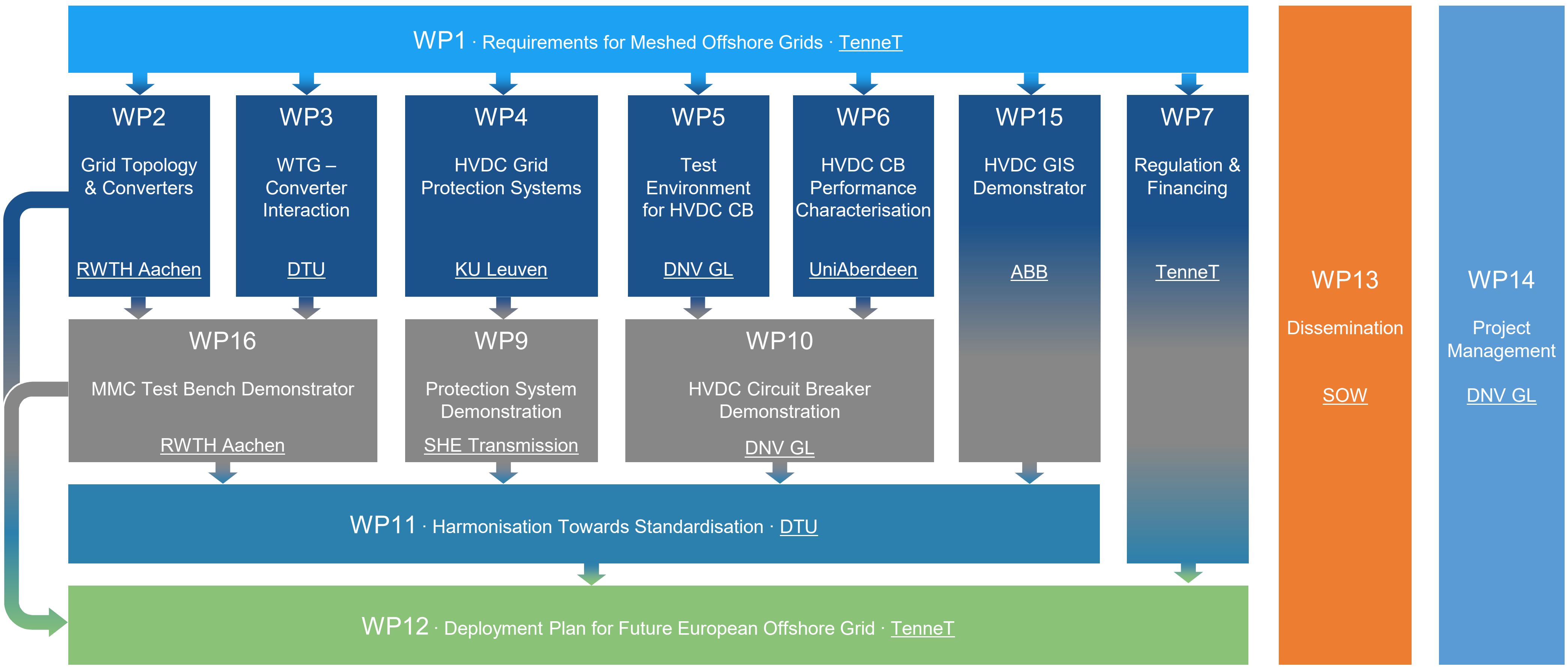
Work Packages



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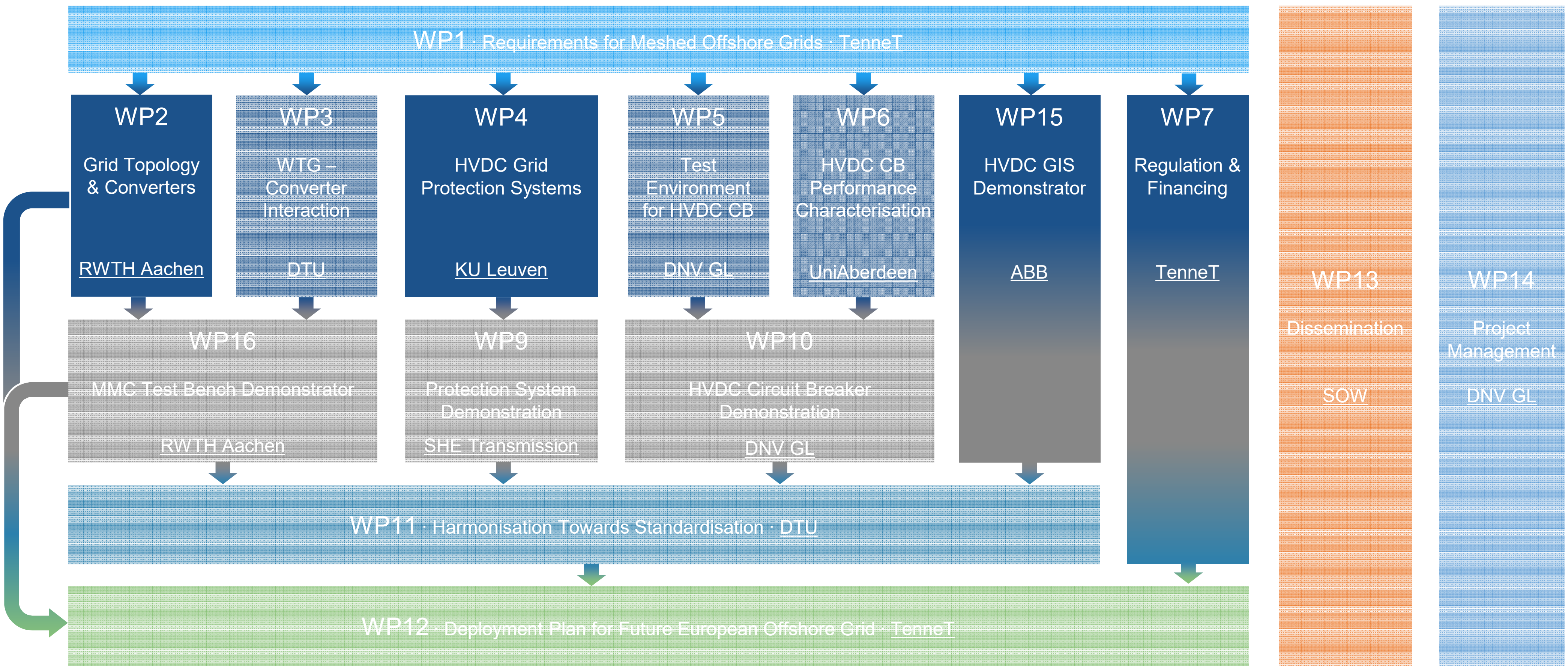
Work Packages



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Objectives WP2 and WP4

WP2: Grid Topology & Converters

- Trade-off analysis of different topologies
- Interconnection of VSC and DRC systems
- Control concepts to ensure interoperability
- To define recommendations on onshore and offshore power systems for existing grid codes

WP4: HVDC Grid Protection System

- Functional requirements for various DC grids
- Evaluate wide range of DC grid protection philosophies
- Develop detailed protection methodologies
- Multi-purpose HVDC protection
- Cost-benefit evaluation

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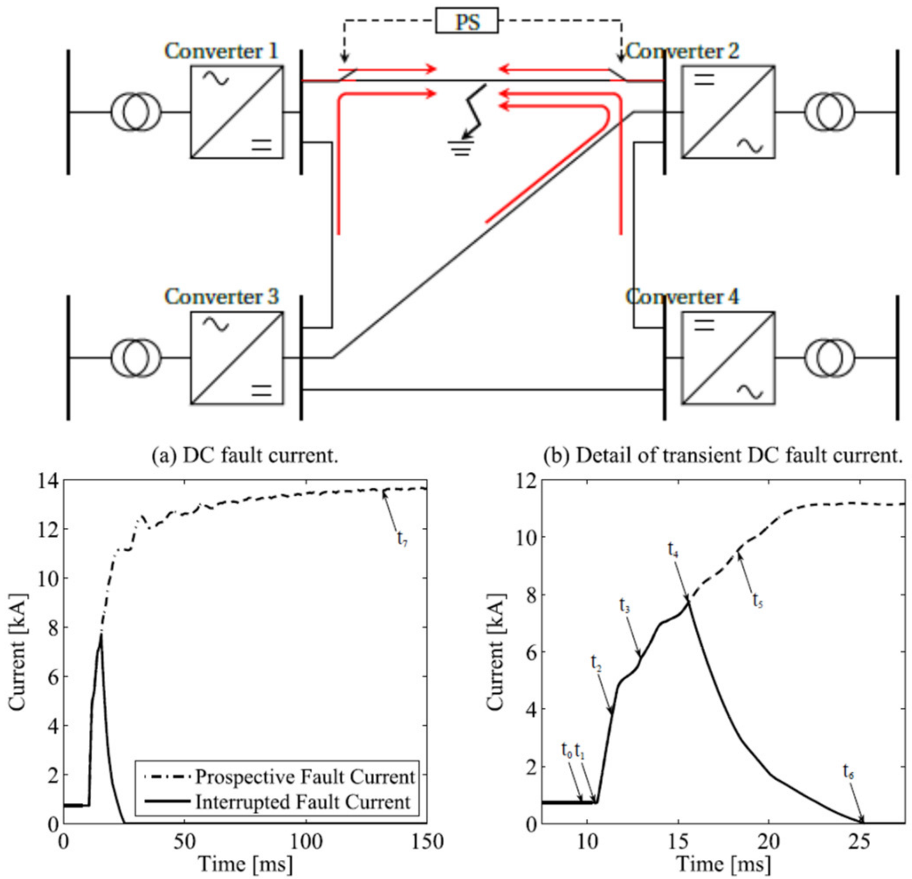
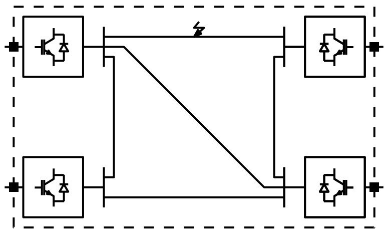
Fault Currents within a DC Grid



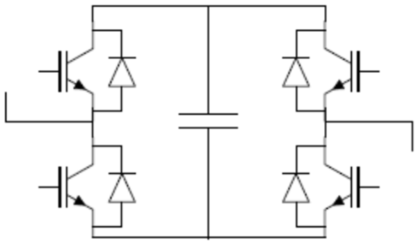
- Fault current characteristics
  - No zero crossings
  - High rate-of-rise
  - High steady state value
- Sensitive (& expensive) converters and fast controls

Different Technologies Exist to Interrupt a DC Fault Current



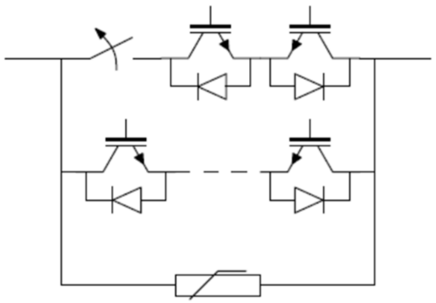
Converter AC breakers

- 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

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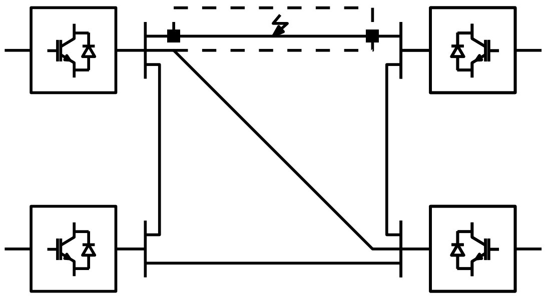
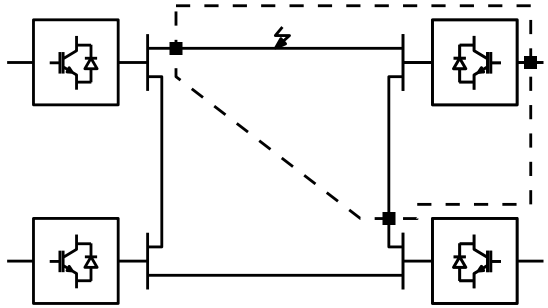
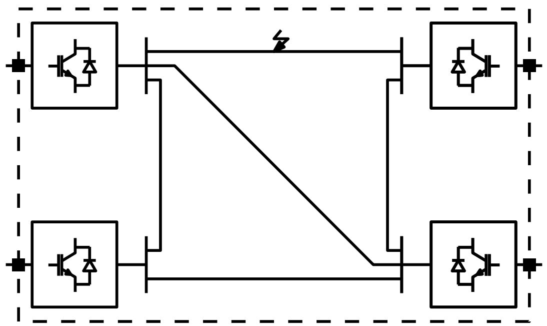
Different Technologies Lead to Various Fault Clearing Strategies



Selective:
Using DC breakers on every line end



Partially selective:
Split DC grid in sub-grids (protection zones)



Non-selective:
Temporary shut down the whole DC grid

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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.

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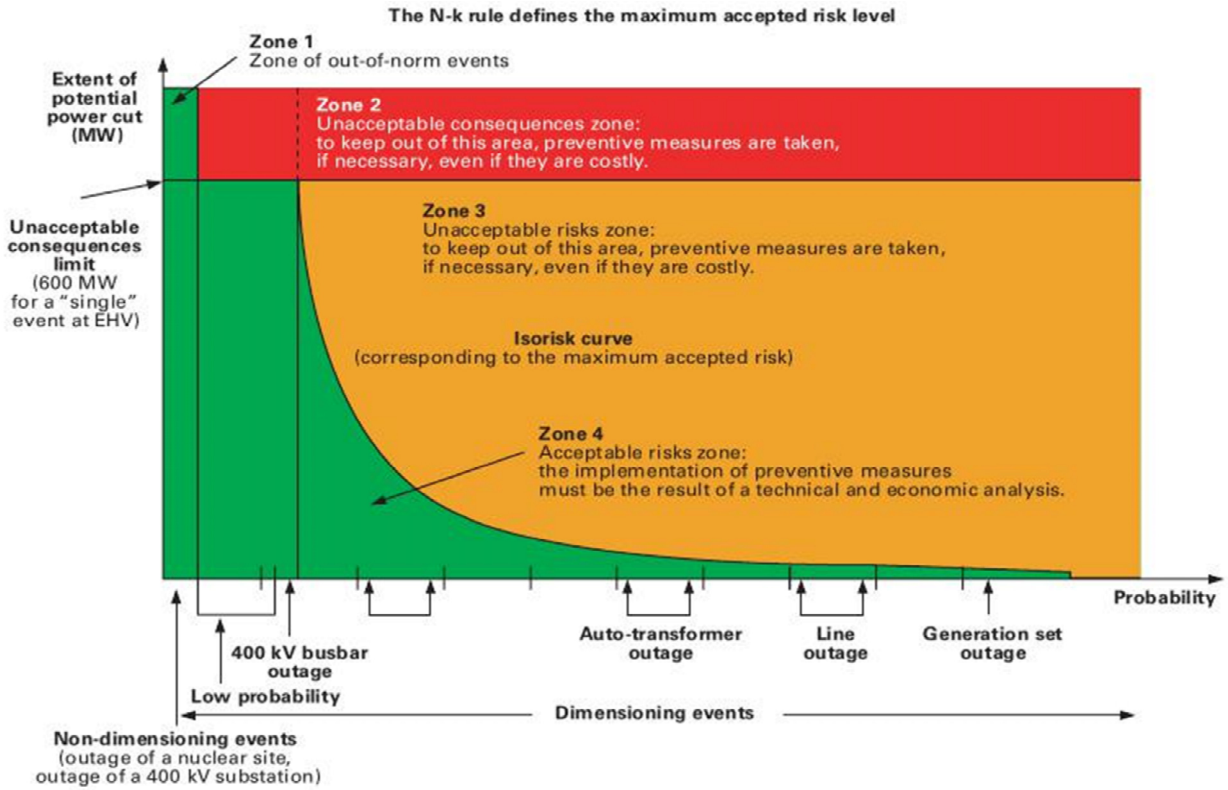
Relevant Fault Causes → Consequences & Probability → Risk



*source: RTE memento on electrical system security now on-line

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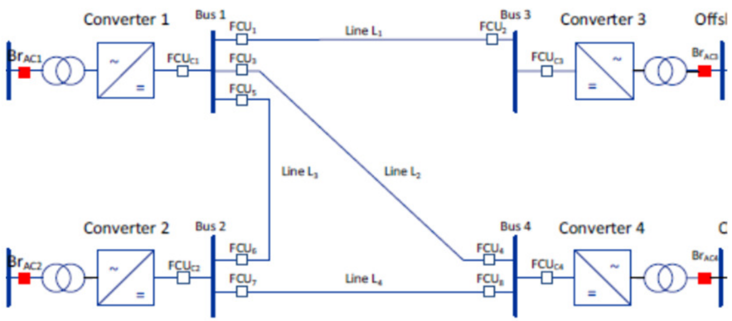
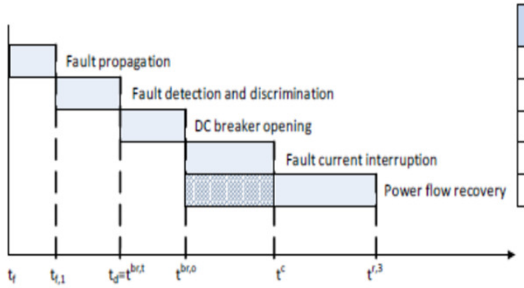
Parameters to Characterize Fault Clearing Strategies





Interval	Duration
t_f-$t_{f,1}$	us to ms
$t_{f,1}$-t_d	us to ms
t_d-$t^{br,o}$	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

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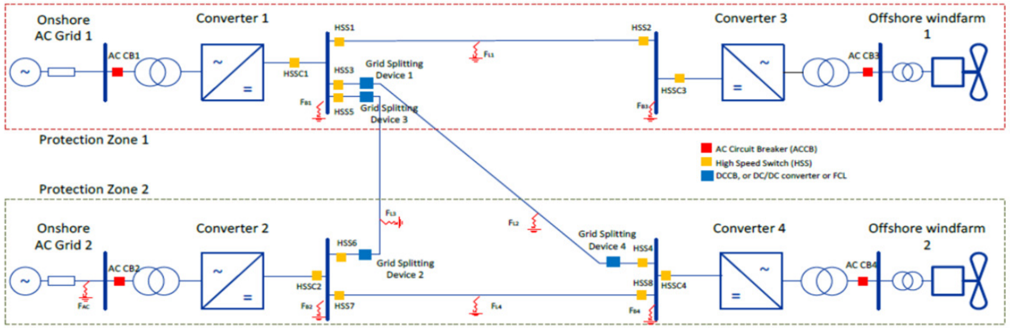
Example Protection Matrix for Partially Selective Strategy



Protection zone		C1	C2	C3	C4	Protection equipment in operation
1	$F_{L1,ptg}$	PS	CO	PS	CO	$DCCB_1$, $DCCB_3$, $ACCB_1$, $ACCB_3$
1-2	$F_{L2,ptg}$	CO	CO	CO	CO	$DCCB_1$, $DCCB_4$
1-2	$F_{L3,ptg}$	CO	CO	CO	CO	$DCCB_2$, $DCCB_3$
2	$F_{L4,ptg}$	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	$F_{B1,ptg}$	PS	CO	PS	CO	$DCCB_1$, $DCCB_3$, $ACCB_1$, $ACCB_3$
2	$F_{B2,ptg}$	CO	PS	CO	PS	$DCCB_2$, $DCCB_4$, $ACCB_2$, $ACCB_4$
2	$F_{B4,ptg}$	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

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Main 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	/	✓	×	×	✓	✓
6	NS FB	Non-Selective	FB	✓	✓	×	✓	✓
7	NS DCCB	Non-Selective	DCCB	✓	✓	×	?[11]	✓
8	NS SFCL	Non-Selective	SFCL	✓	✓	×	?[11]	✓
10	Open Grid	Non-Selective	DCCB	✓	✓	×	?[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

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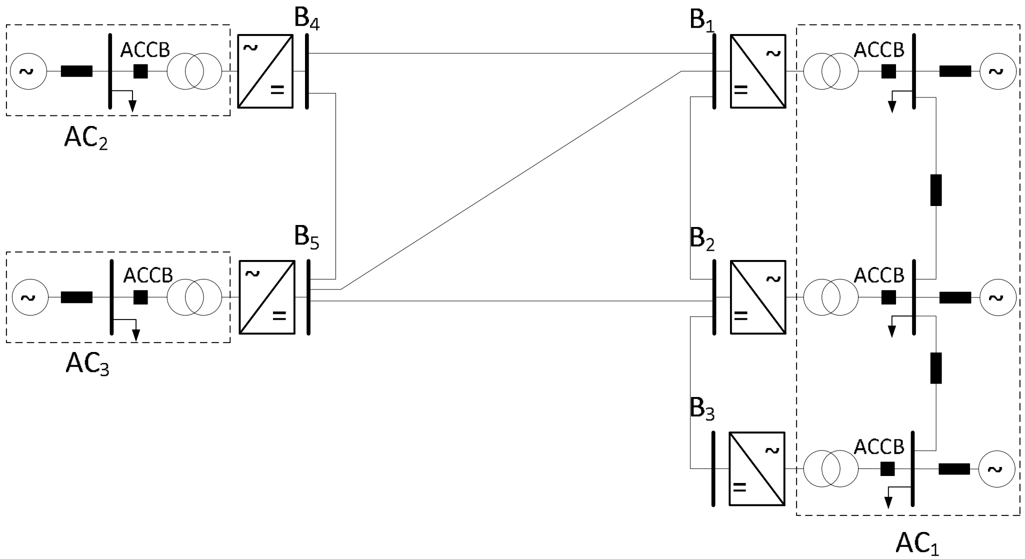
BC16

Impact on the PoC – AC

- Exemplary DC grid contigencies
  - Converter outtage
  - DC line fault

- Exemplary fault clearing strategies for line faults
  - Non-selective using AC breakers
  - Non-selective using fault-blocking converters
  - Seletive using HVDC circuit breakers



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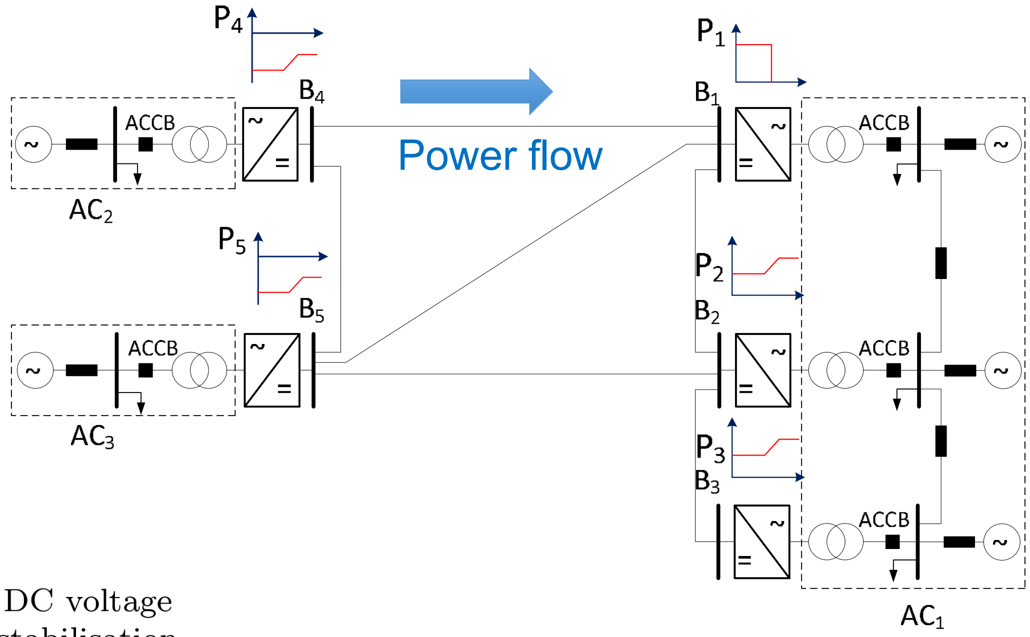
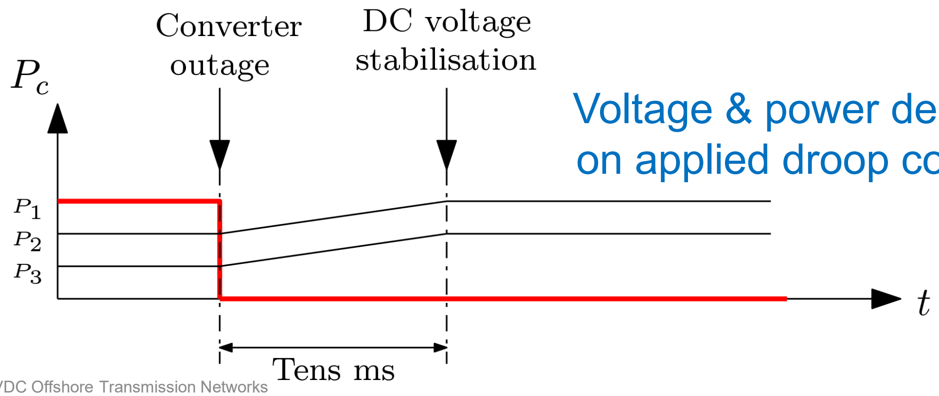
Folie 14

BC16 I propose to give an overview slide before diving into the examples.
Brantl, Christina; 27.02.2019

Converter outage

- Impact on DC grid
  - Power imbalance
  - Voltage variation
- Impact on AC grids
  - Loss of power transfer
  - Loss of generation/load





Voltage & power depend on applied droop control

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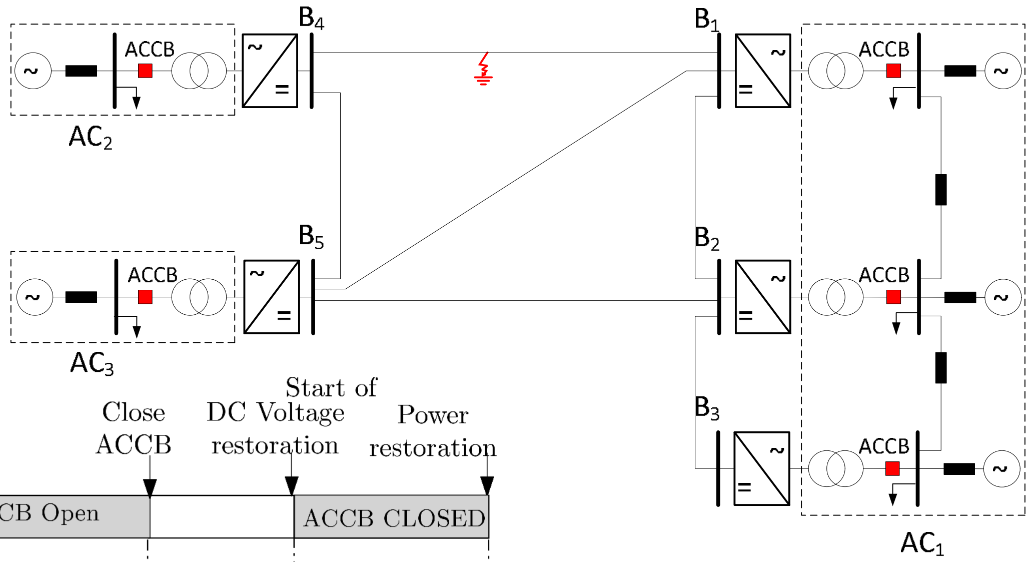
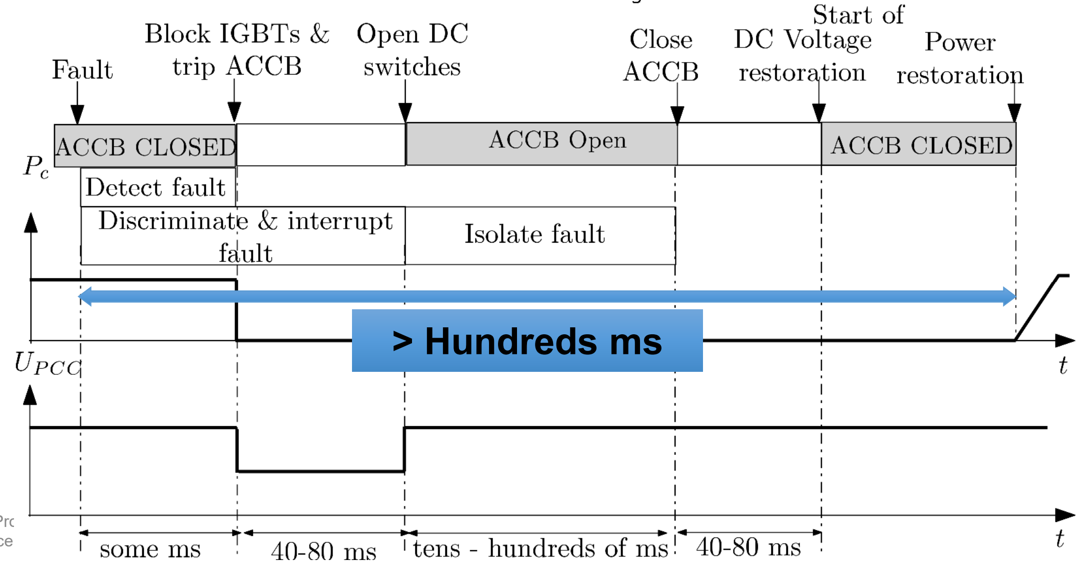
DC line fault using non-selective fault clearing (AC circuit breakers)

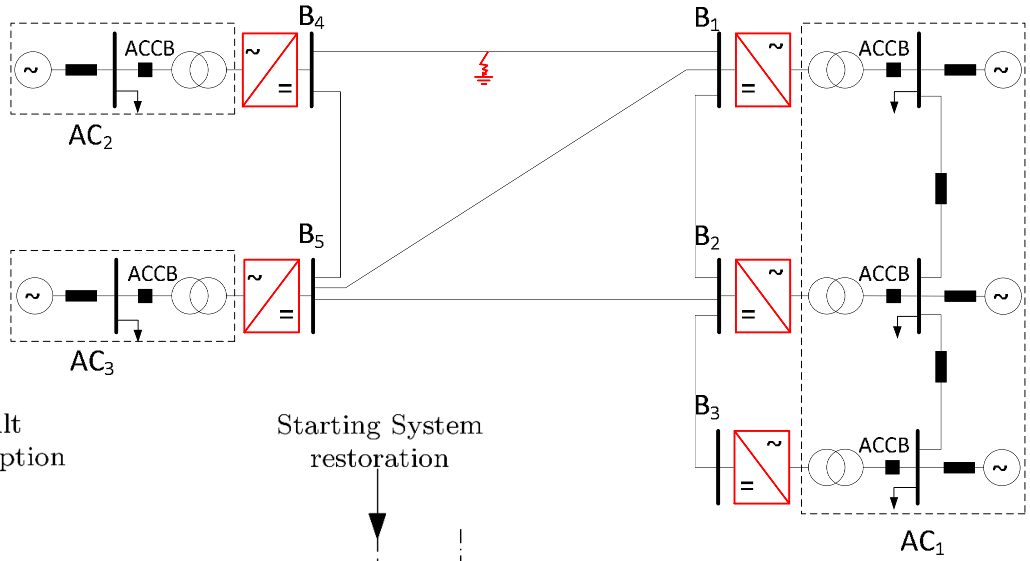
- Impact on DC grid
  - Loss of whole DC grid
- Impact on AC grids
  - Loss of generation/load

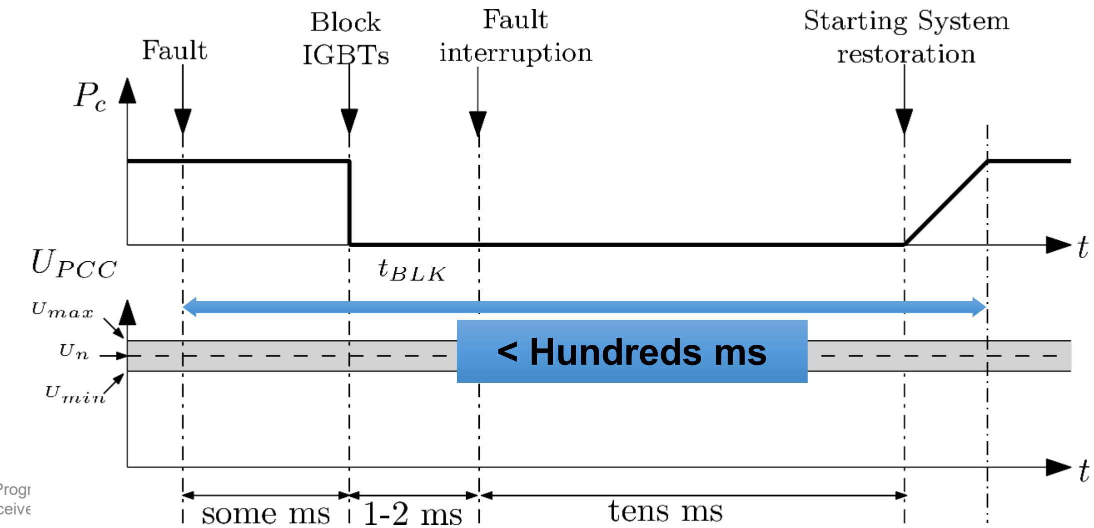




DC line fault using non-selective fault clearing (converter with fault blocking capability)

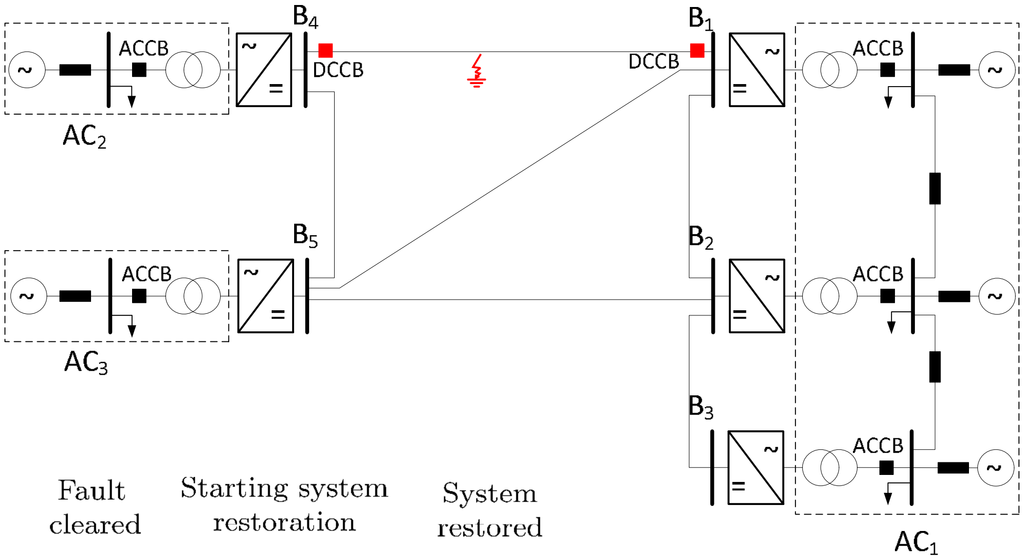
- Impact on DC grid
  - Temporary loss of whole DC grid
- Impact on AC grids
  - Loss of generation/load

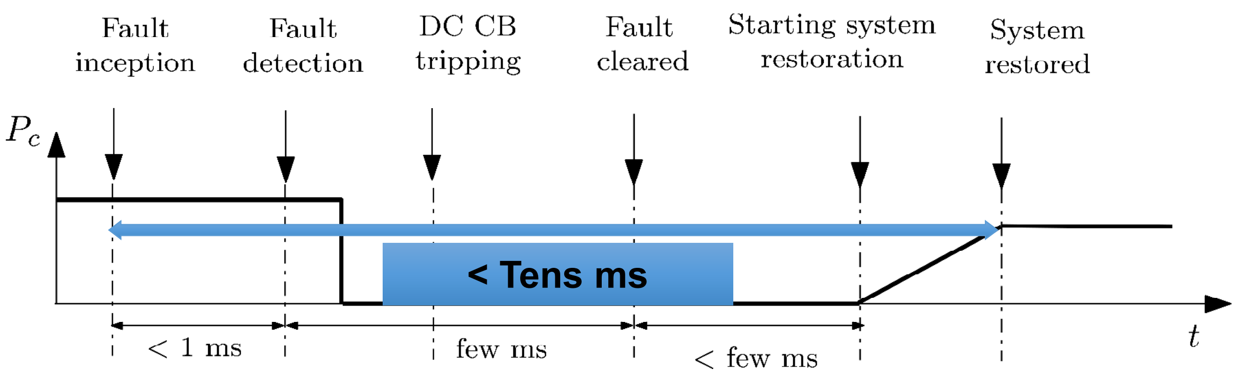




DC fault using fully selective fault clearing

- Impact on DC grid
  - Temporary power & voltage transient
- Impact on AC grids
  - Very short transient





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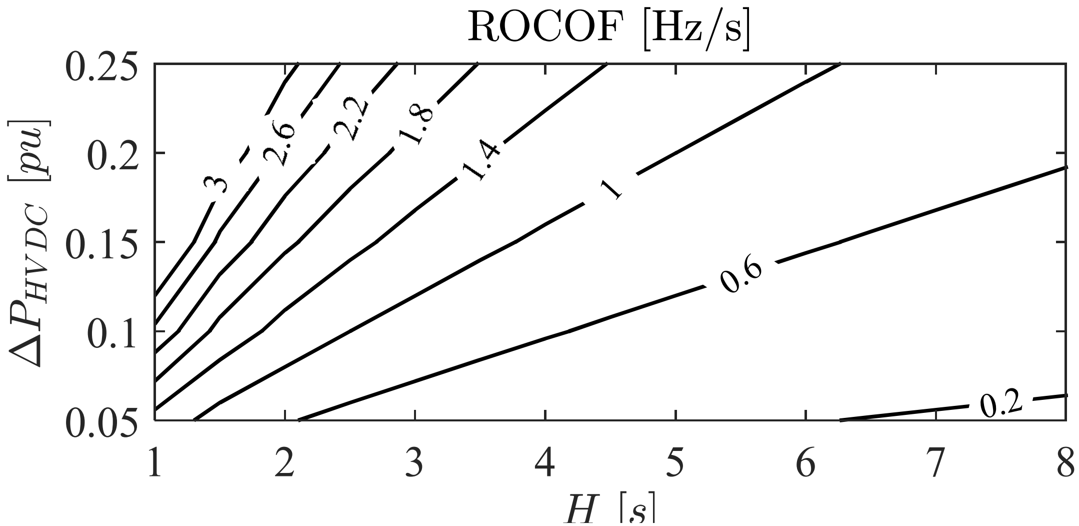
Impact on AC frequency stability

- Parameters
  - Inertia constant H: 1-8
  - $\Delta P_{HVDC} = 0.05 - 0.25\ pu$
  - $\Delta \mathrm{T}_{\mathrm{HVDC}} = 0.1 - 2s$
- ROCOF mainly depends on system Inertia & $\Delta \mathrm{P}_{\mathrm{HVDC}}$



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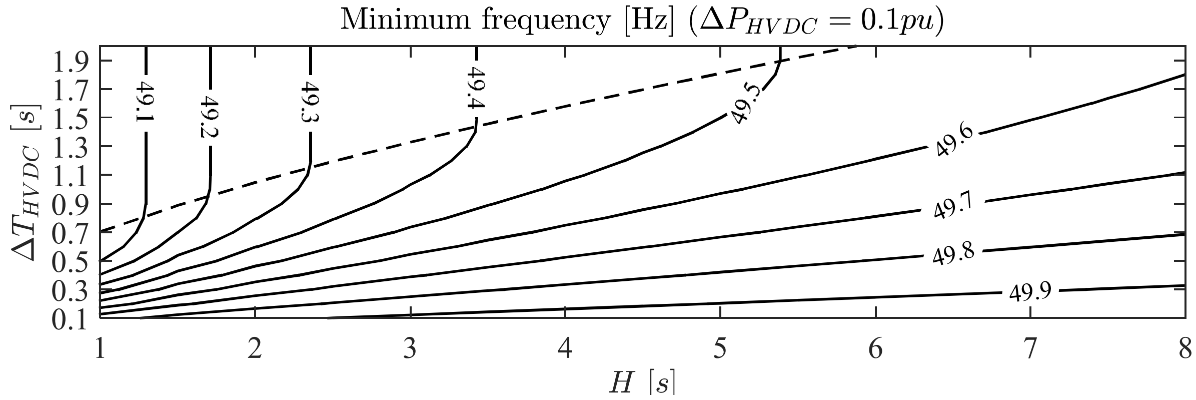
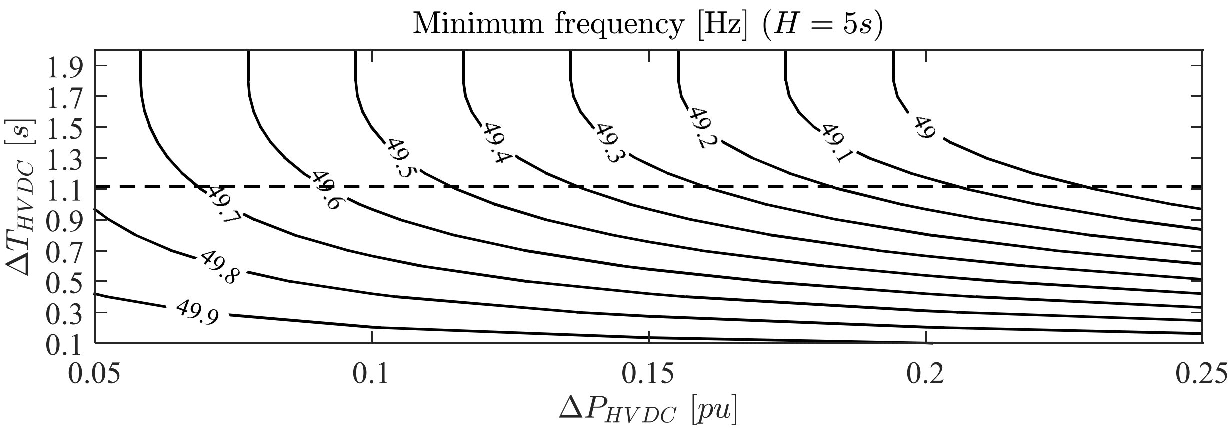
Impact on AC frequency stability

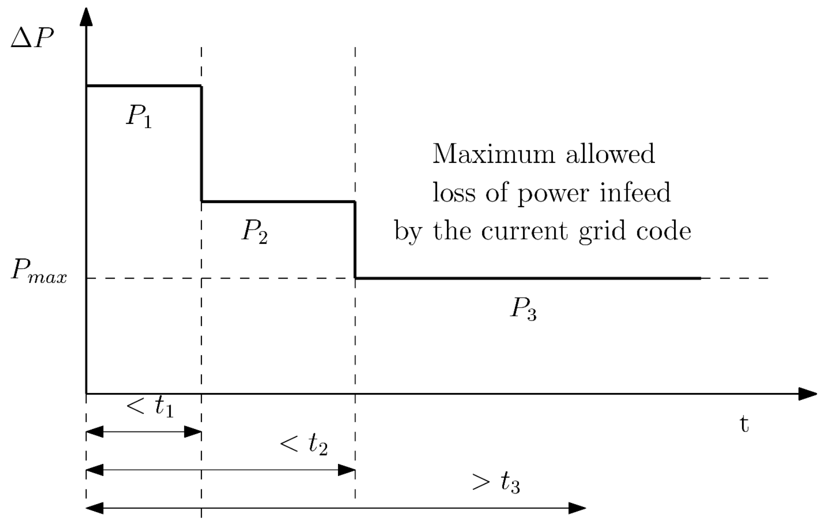
- Minimum instantaneous frequency (f_{min}) increases if power is quickly restored
  - Maximum allowed power restoration time





Possible future AC grid code

- Current AC grid code only defines maximum allowed permanent loss
  - E.g. UK grid code: That level of loss of power infeed risk which is covered over long periods operationally by frequency response to avoid a deviation of system frequency outside the range 49.5Hz to 50.5Hz for more than 60 seconds. Until 31st March 2014, this is 1320MW. From April 1st 2014, this is 1800MW.
- Possible future AC grid code:
  - Transient loss P_1: restoration within t_1 (e.g. one cycle)
  - Temporary loss P_2: restoration within t_2 (e.g. hundreds ms)
  - Permanent loss P_3: equal to maximum allowed permanent loss



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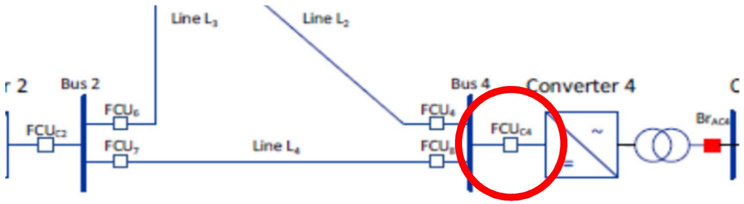
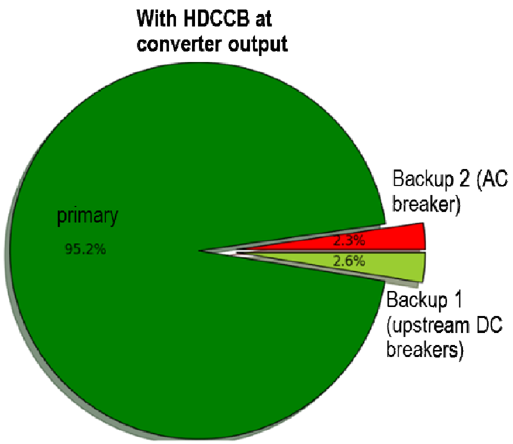
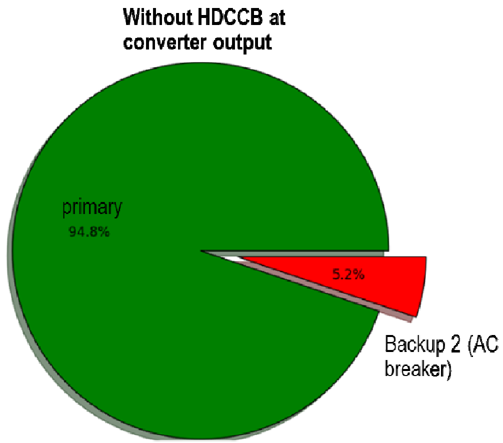
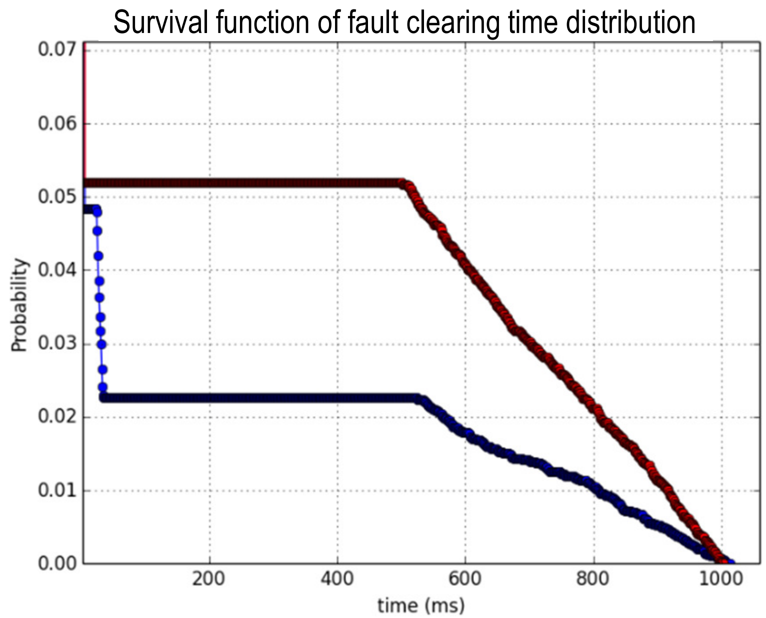
Next Tasks: Comparing Costs and Benefits of Strategies



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







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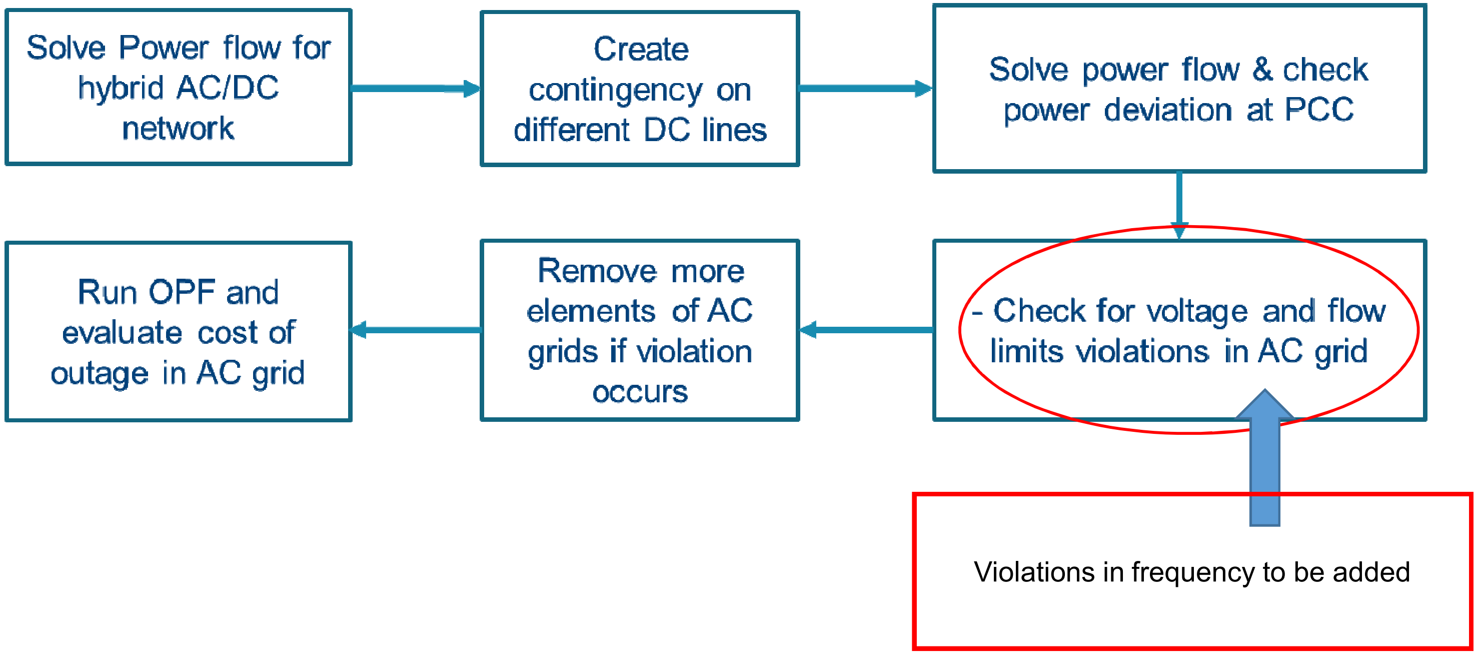
Overall Methodology CBA



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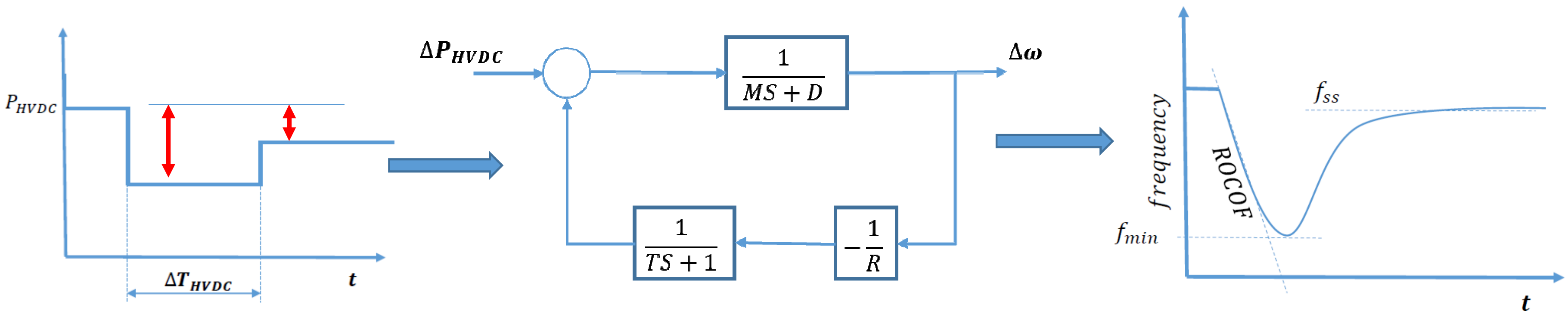
CBA of power system with DC protection Frequency deviation calculation

Frequency deviation can be calculated using following model:



- Use of probabilistic restoration time into account (ΔT_{HVDC})
- Based on ΔT_{HVDC} and ΔP_{HVDC}, f_{min}, f_{ss}, and $ROCOF$ can be calculated (using Simulink model)
- Assumed limits to determine frequency violations:
  - ROCOF: 0.5 Hz/sec
  - f_{min}: 49.2 Hz
  - Δf_{ss} : 49.8 Hz

➢ Abedrabbo M, Wang M, Tielens P et. al, Impact of DC grid contingencies on AC system stability

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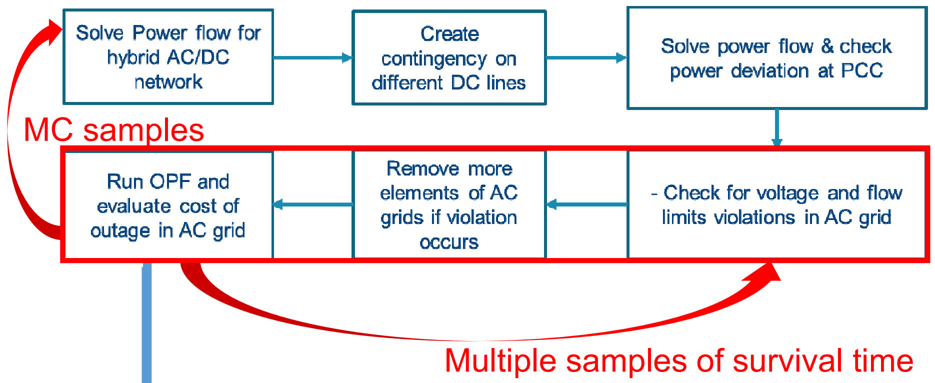
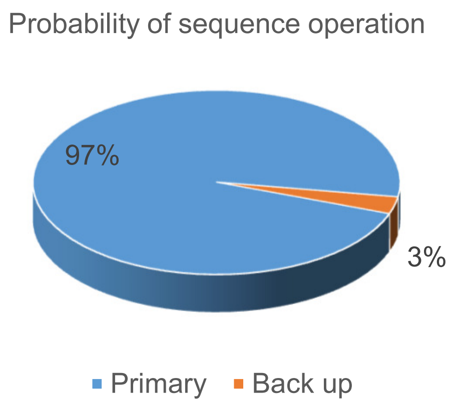
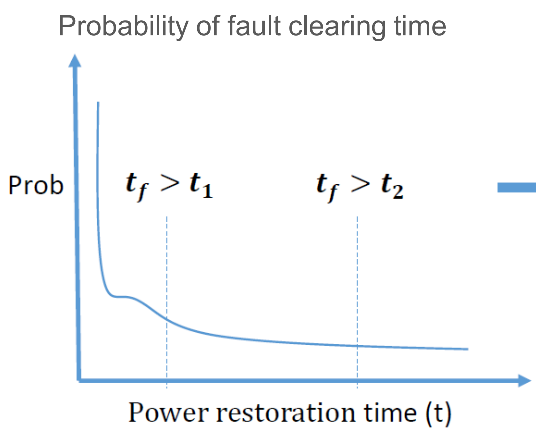
Combining into a probabilistic CBA



- Taking probabilistic fault clearing into account
- Different fault types: pole-to-pole, pole-to-ground, busbar, backup (N-2),…





Cost1*	**P1=**	**C1**
Cost2*	P2=	C2
•	•	•
•	•	•
•	•	•
Costn*	Pn=	Cn
Total cost=		Sum(all)

Next step: applying method to realistic systems

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Conclusions & Discussion

- DC grids connected to AC grids
  - Inertia change will influence DC grid design
  - In particular DC protection
  - But also interaction between DC grid and AC system(s) during transients
- Different protection strategies exist: having different impact on connected system
- CBA which takes into account probability of occurrence and impact into account is developed

- Discussion:
  - How will the max loss of infeed change with decreasing inertia?
  - How much loss of power can we accept on a short time frame (can we loose 10 GW for 100 ms)?
  - Can a DC grid with multiple converters connected to a single synchronous zone excite instabilities due to changing injections during faults?
  - Do we have the models to analyse these problems?
  - How many pan-European blackouts per century do we accept?

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Any Questions?

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