DC grid protection and Cost-Benefit Assessment – DC CB cost models

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Presentation outline

Need for a Cost Performance Assessment approach for protection system analysis

How to capture protection system performances?

How to capture cost of protection system?

A methodology for DC CB cost parametric model development

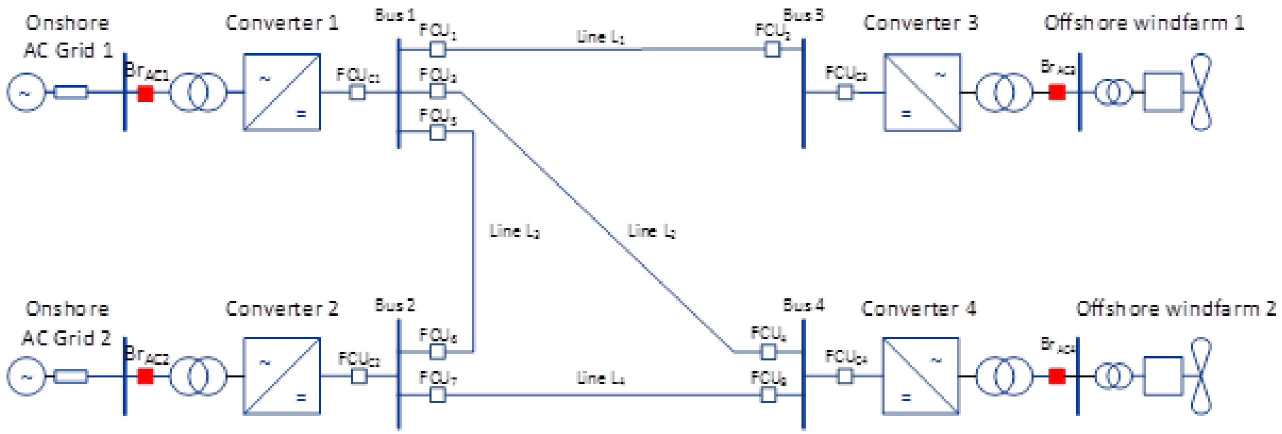
An application to a four terminal meshed DC grid (WP 4.3 benchmark)

Conclusions & Perspectives

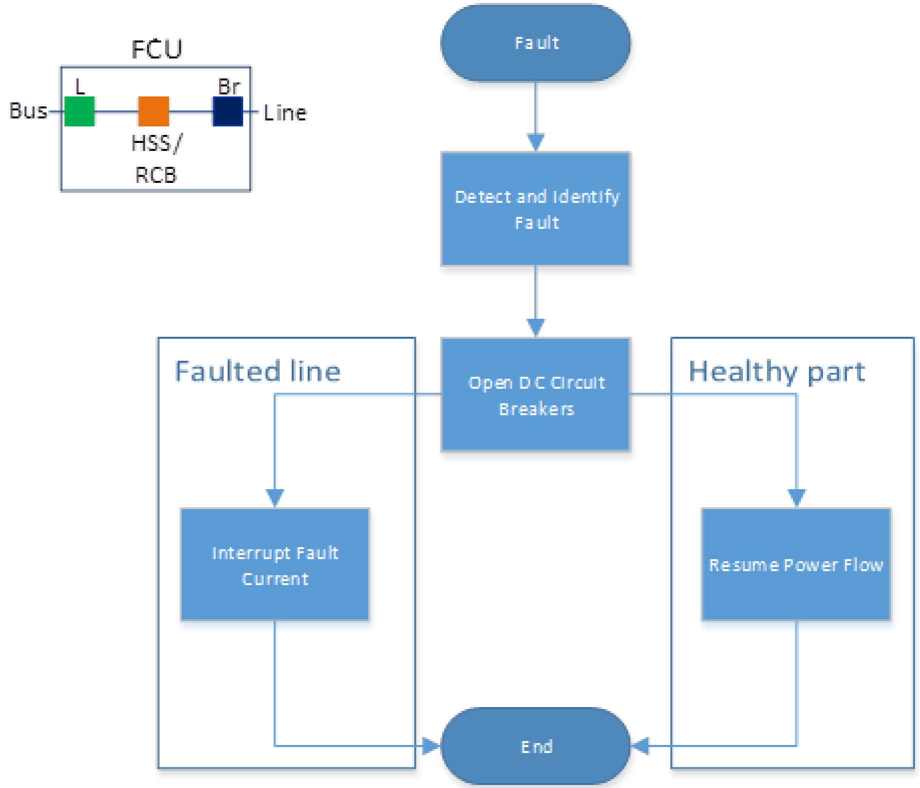
Main technical requirements for HVDC grid Protection

1. **Reliability**: The faulty line must be isolated
2. **Selectivity**: Only the faulty line must be isolated
3. **Speed**: To comply with fast rise of DC fault current
4. **To guarantee DC and AC systems stabilities** after fault clearing and power restoration process

Acts as in AC system with Full Selective Fault Clearing Strategy



Primary sequence flow chart



1. Need high speed DC breaker (e.g. hybrid DC CB)
2. Require DC reactor to limit the DC fault current rise
3. High level of energy has to be dissipated by surge arresters
4. Is expected to have low power interruption at AC side interfaces: Expected limited impact on AC network stability
5. **High cost can result**

But do we always need to be very fast?
Could we be only fast?

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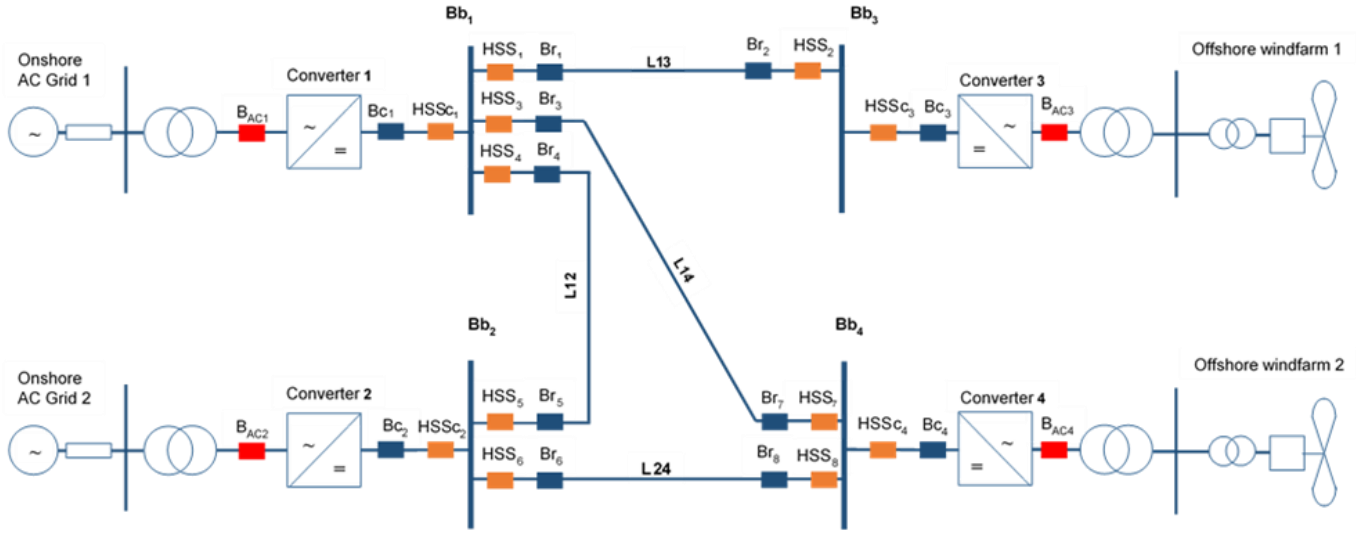
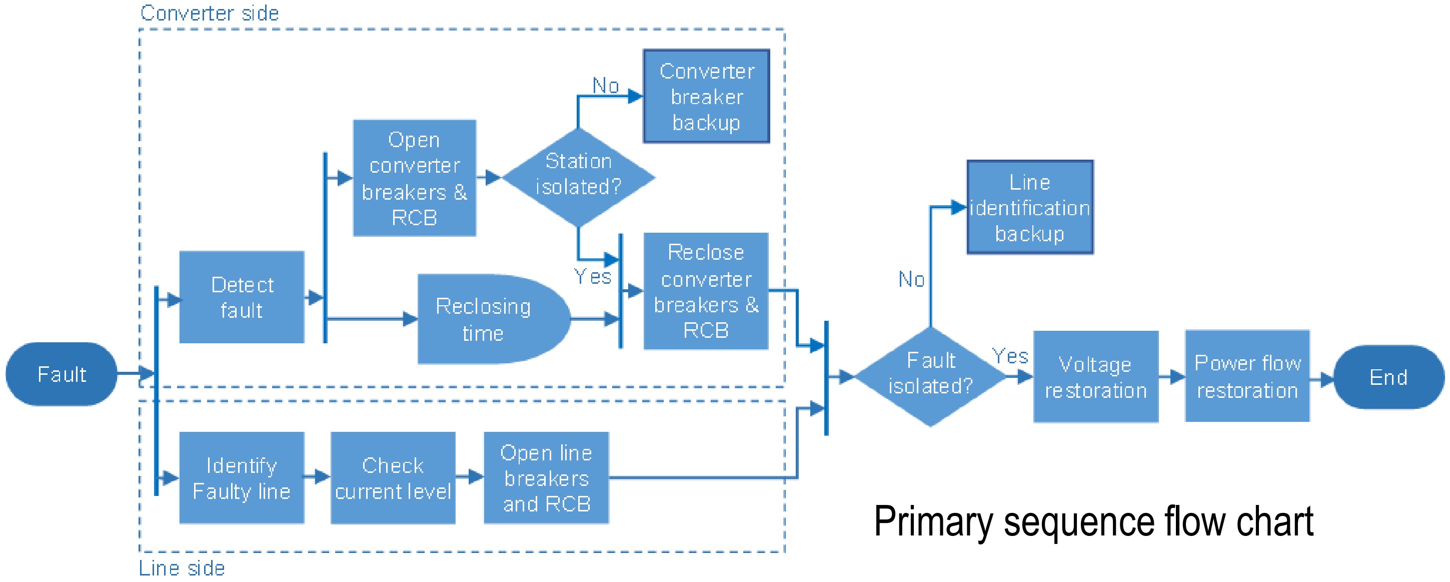
Non-selective Strategies: Converter Breaker Fault Clearing Strategy





Primary sequence flow chart

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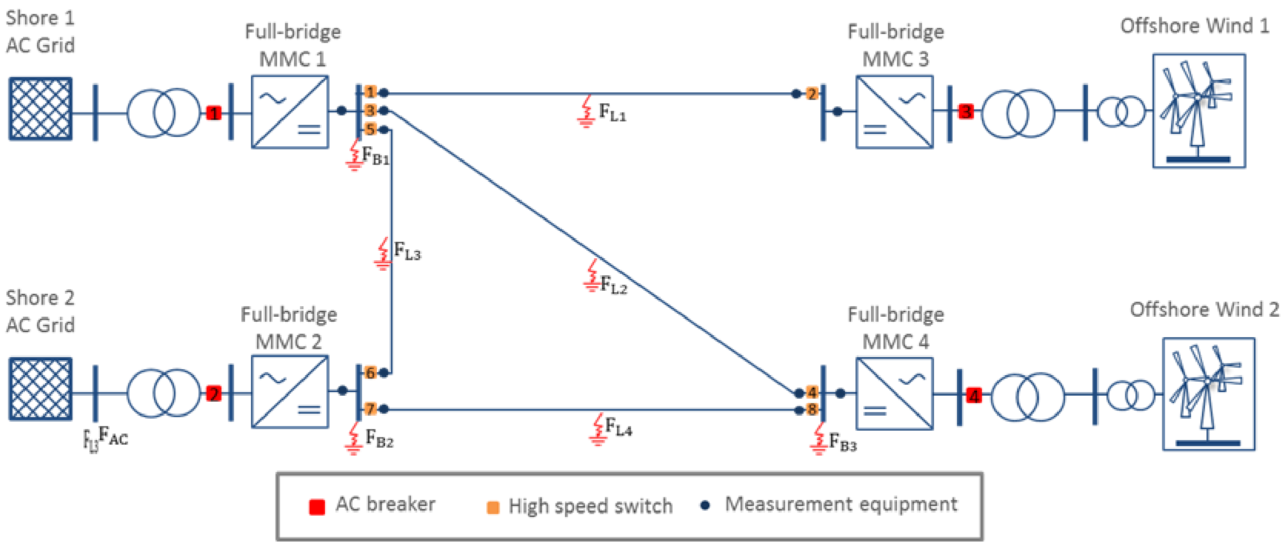
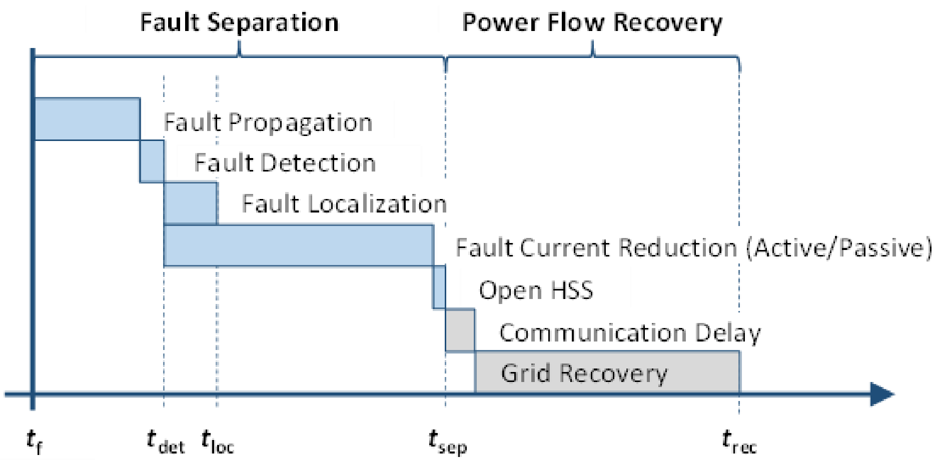
Non-selective Strategies: Fault Blocking Converter based Fault Clearing Strategy





Primary sequence time chart

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Non-selective Fault Clearing Strategies

1. Need lower speed DC breaker (e.g. mechanical DC CB)
2. Do not require DC reactor
3. Very low level of energy has to be dissipated by surge arresters
4. Need to ensure both voltage and power restoration at all AC side interfaces: Expected higher impact on AC network stability
5. **Lower cost can be expected**

Protection system required performances need first to be considered, to comply with system level requirements

It could be over expensive to always implement the most performant strategy

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How to capture protection strategy performances: Key Performances Indicators (KPIs)

Key Performance indicators

Efficiency Indicators

Failure Indicators

Efficiency Indicators are used to express the impacts that the fault clearing performed can cause

Examples

- **Fault clearing time**
- Time to restore DC Voltage
- **Ready to restore P time**
- Ready to restore Q time
- Energy unbalance from AC system
- Frequency deviation in AC system

Failure indicators express the features related to the non-correct functioning of a protection strategy

These indicators are used to infer the “**Reliability**” of a protection strategy

Examples

- **Backup Probability**
- **Non-cleared fault probability**
- Outages due to security failures

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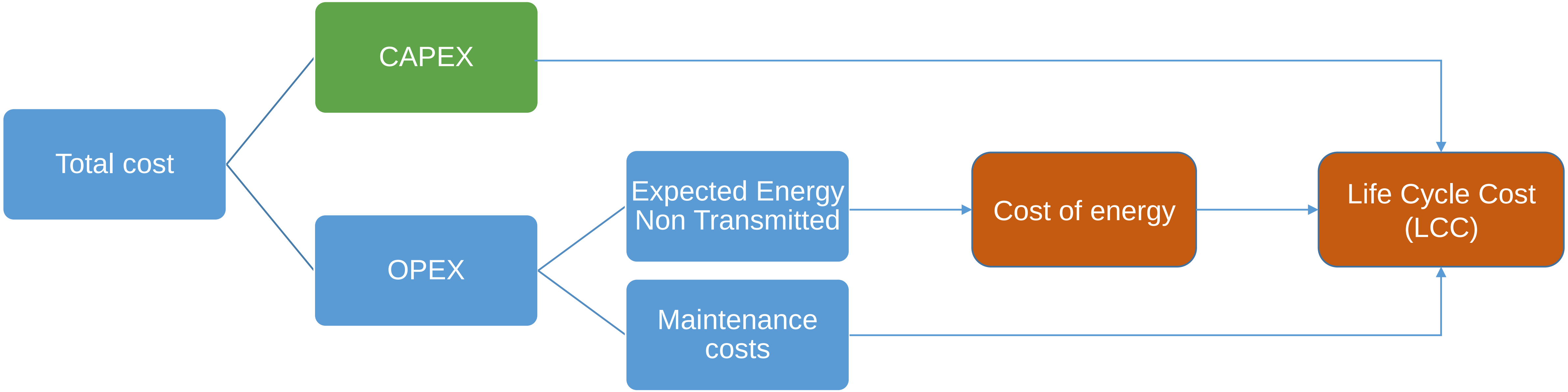
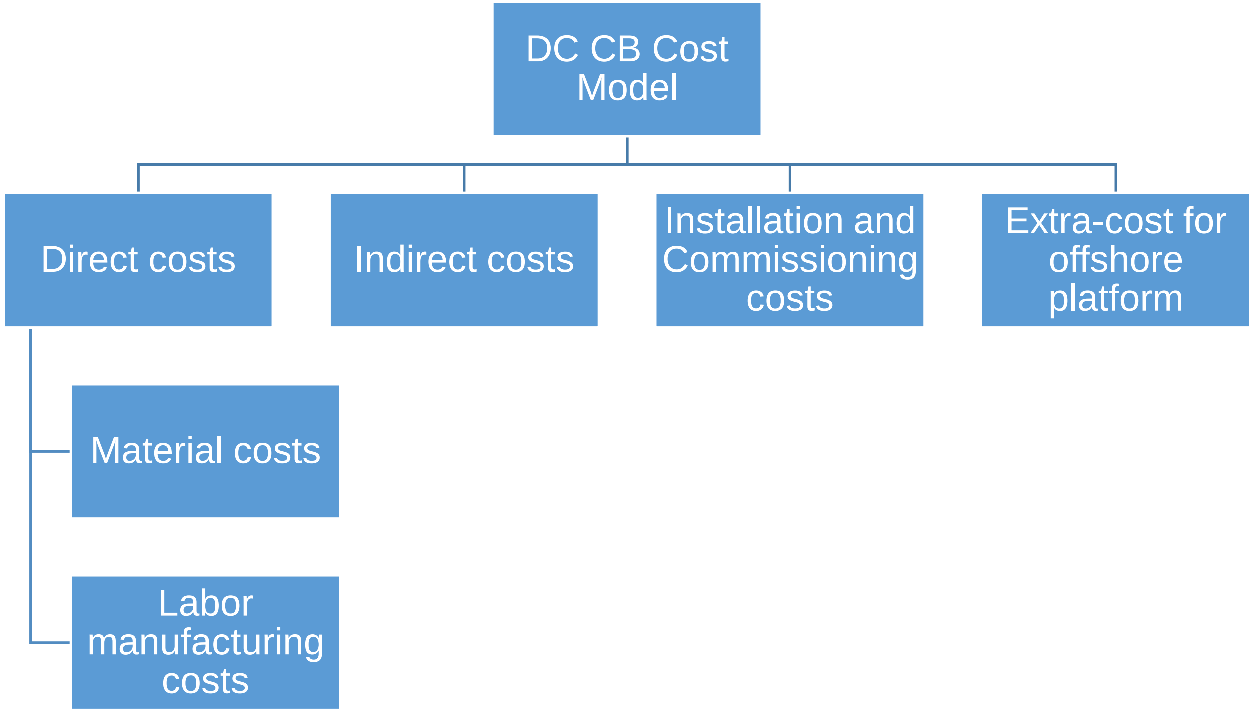
How to capture protection strategy costs



DC CB cost parametric modeling framework implemented within PROMOTioN Project

A bottom-up process



DC CB cost model breakdown

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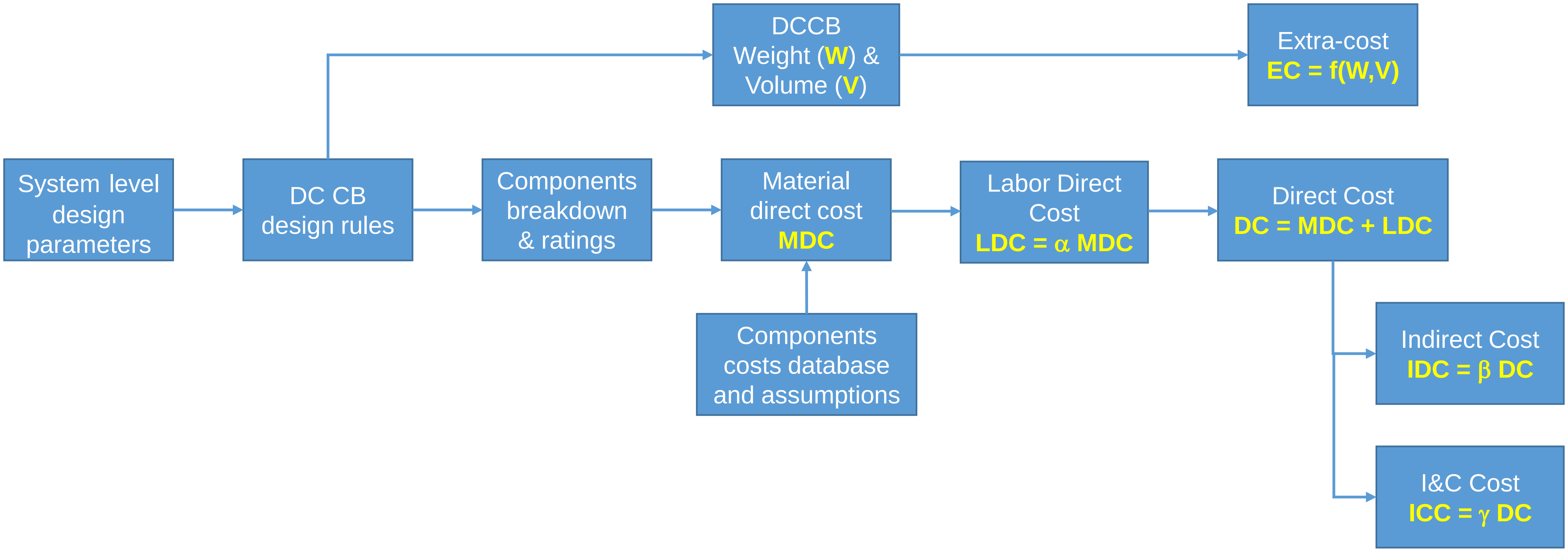
DC CB cost parametric modeling framework implemented within PROMOTioN Project



DC CB cost = DC + IDC + ICC + EC

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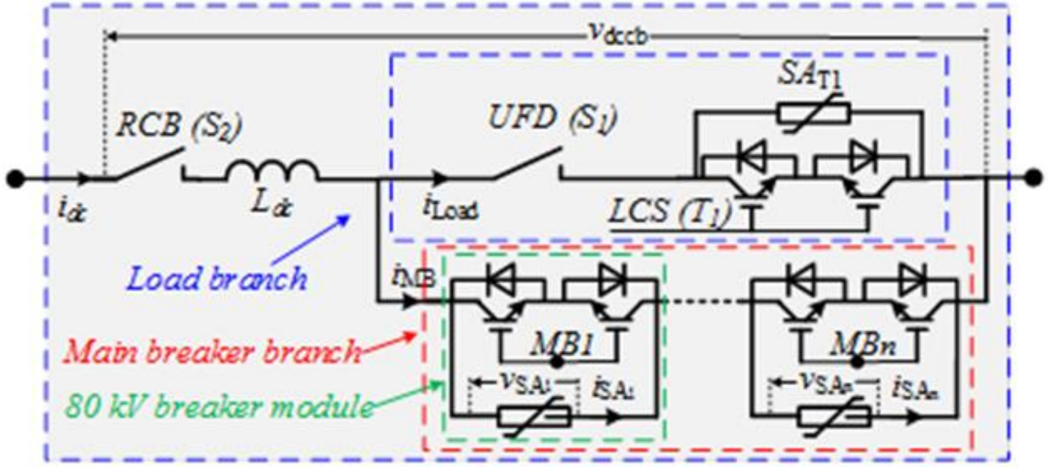
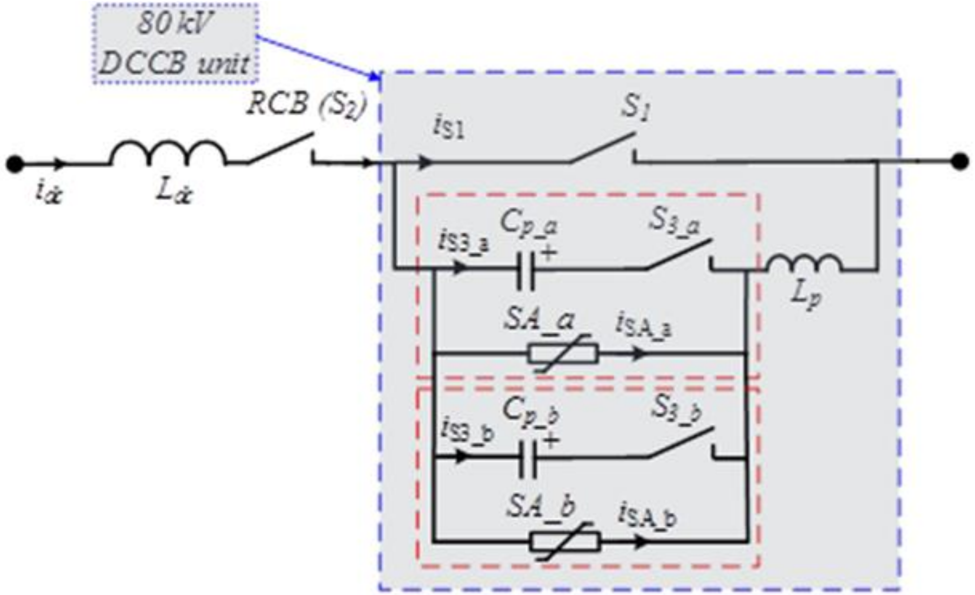
DC CB cost parametric model development: Two technologies considered



Hybrid DC CB



Mechanical DC CB

Nominal pole to ground DC voltage	U
Transient Interruption Voltage (TIV) peak value (Maximum voltage between the two terminals during the breaking process)	U_{brM}
Maximum DC breaking current	I_{brM}
Maximum DC permanent / operating current	I_n
Breaker opening time at maximum DC breaking current (Time from breaker trip signal to current diversion to energy dissipators)	T_o
Maximum Energy Dissipation (Maximum electromagnetic energy that can be dissipated during one cycle of the breaking process)	E
Current limiting DC reactor	Ldc

Main system level parameters

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DC CB cost parametric model development: Study case

Input parameter	Abb.	Non-selective converter breaker with mechanical DC CBs	Full selective with mechanical DC CBs	Full selective with hybrid DC CBs
Maximum DC permanent / operating current	I_n	2 kA	2 kA	2 kA
Maximum DC breaking current	I_{brM}	16 kA	16 kA	16 kA
Nominal pole to ground DC voltage	U	320 kV	320 kV	320 kV
Transient Interruption Voltage (TIV) peak value	U_{brM}	480 kV	480 kV	480 kV
Maximum Energy Dissipation	E	1 MJ	50 MJ	10 MJ
Breaker opening time at maximum DC breaking current	T_0	8 ms	8 ms	2 ms
Current limiting DC reactor	Ldc	0 mH	200 mH	100 mH
Opening/Closing cycle		OCO	OCO	OCO
Directionality		Bi-directional	Bi-directional	Bi-directional

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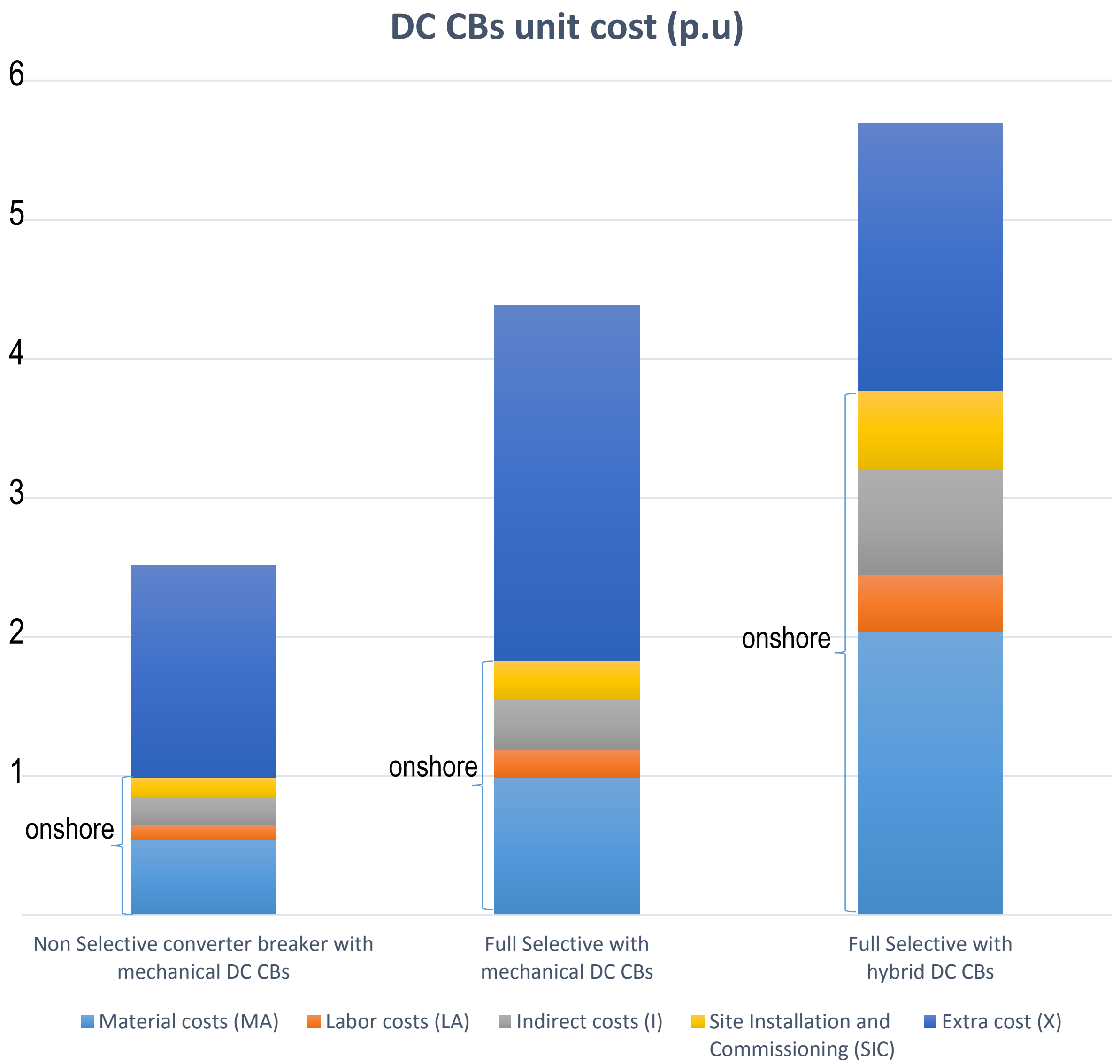
DC CB cost model development: Study case



For onshore location, DC CB cost varies from 1 to ~4

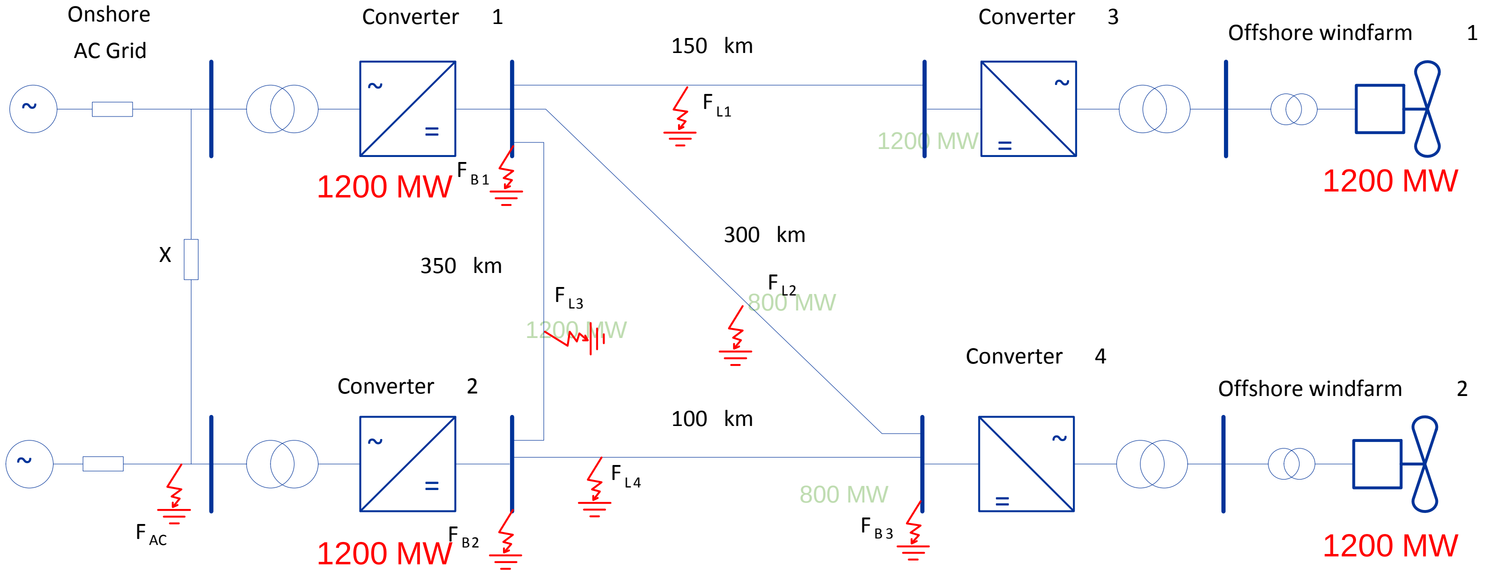
Material cost goes from 1 to 4 from M DC CB for converter breaker to hybrid DC CB: Impact of PE components costs (H DCCB) and large DC reactor and SA (M DC CB for full selective)

Extra costs for offshore location are quite significant

For offshore location, DC CB cost varies from ~2.5 to ~5.5

Application to WP4 benchmark: Benchmark & Assumptions

Main input parameters
Nominal voltage: 320 kV
Converter configuration: Bipolar with earth return or symmetric monopole



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Application to WP4 benchmark: DCCBs main specifications

Input parameter	Parameter	Full-selective	Full-selective	Converter breaker	Full-Bridge
Technology		Hybrid	Mechanical	Mechanical	Mechanical
Maximum DC permanent / operating current	In	2 kA	2 kA	2 kA	2 kA
Maximum DC breaking current	IbrM	9 kA	16 kA	20 kA	2 kA
Nominal pole to ground DC voltage	U	320 kV	320 kV	320 kV	40 kV
Maximum Energy Dissipation	E	10 MJ	50 MJ	1 MJ	1 MJ
Breaker opening time at maximum DC breaking current	T0	2 ms	8 ms	8 ms	8 ms
Current limiting DC reactor	Ldc	125 mH	200 mH	0 mH	0 mH
Opening/Closing cycle		OCO	OCO	OCO	OCO
Directionality		Bi-directional	Bi-directional	Bi-directional	Bi-directional
Total number of DCCBs		24	24	24	16

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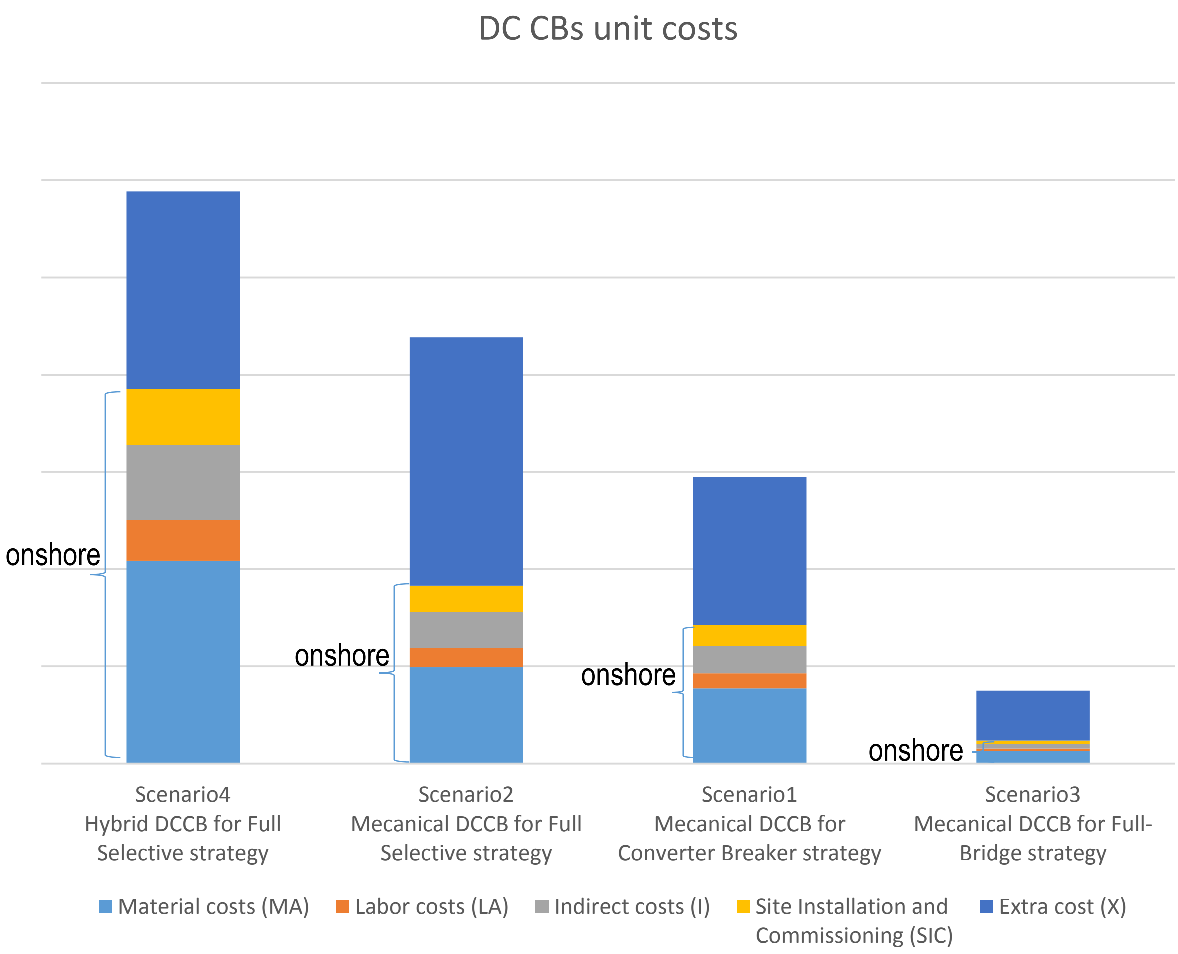
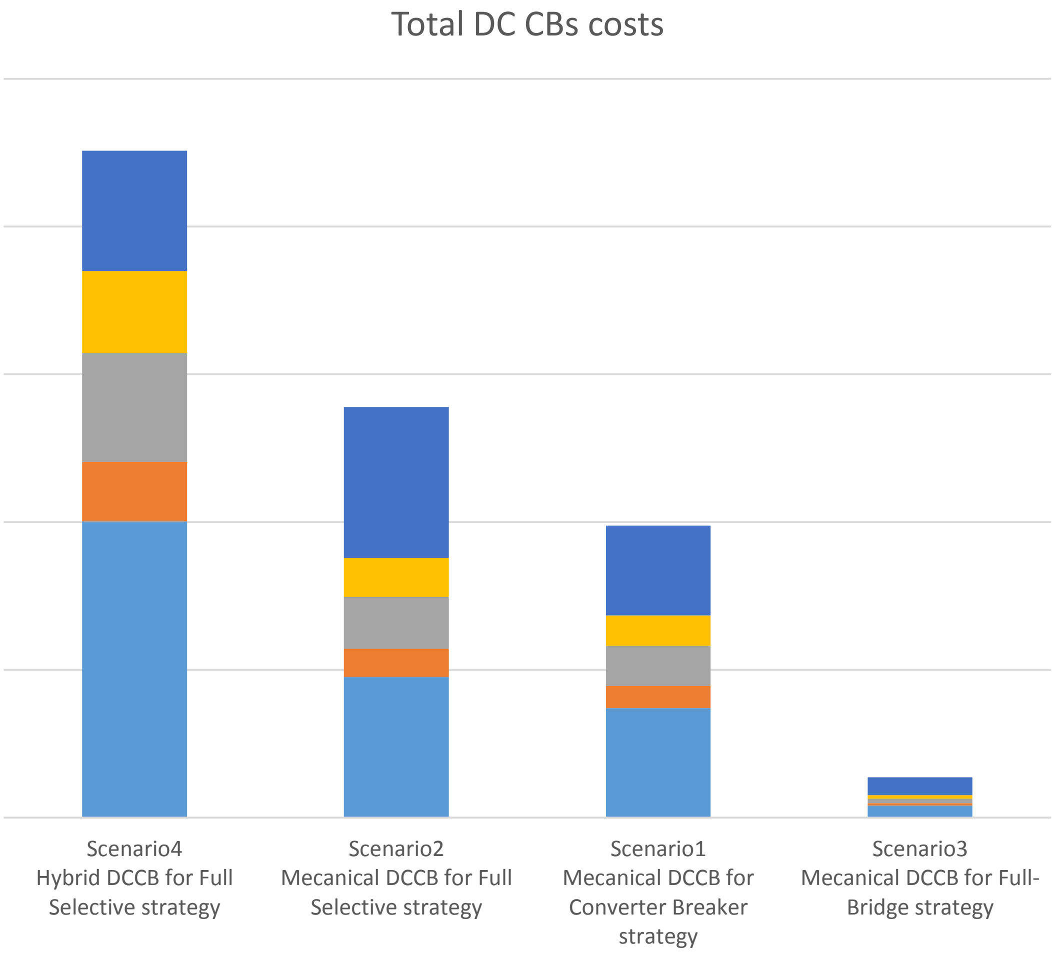
Application to WP4 benchmark: Economic KPIs





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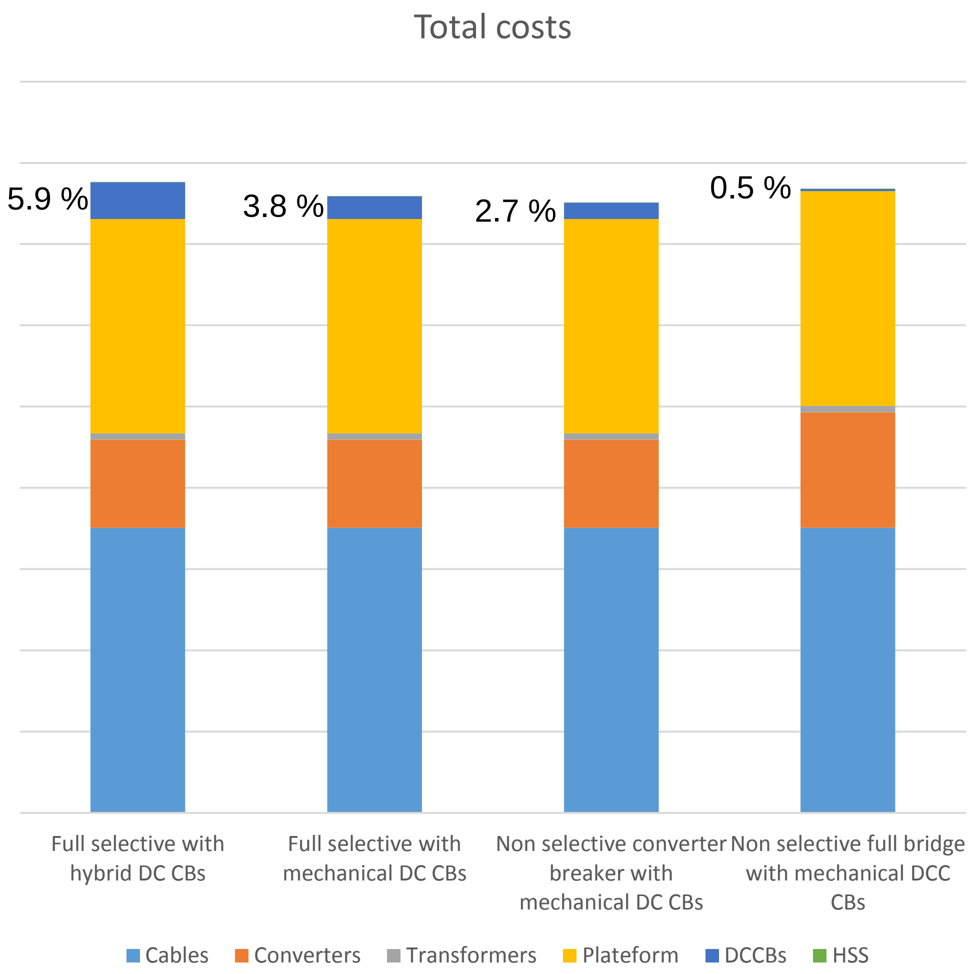
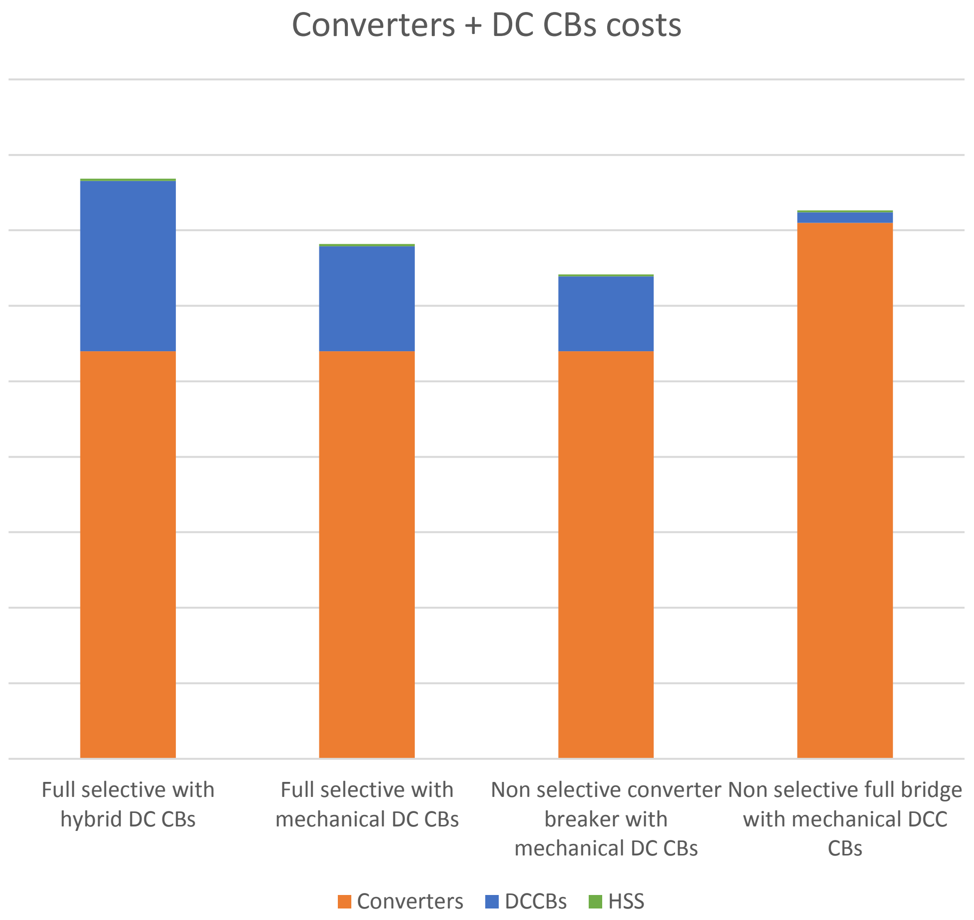
Application to WP4 benchmark: Economic KPIs





Cost of protection equipment is within the range of 0.5 % to 6 % of total cost

Converter extra-cost must be considered for FB converter fault clearing strategy

For offshore DC grids with cables, both cables and platforms costs are dominant: Cost proportion for protection is then lowered

It would be probably different for onshore DC grids containing mainly OHL: Cost proportion for protection should be higher

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Application to WP4 benchmark: Efficiency KPIs

Test conditions for EMT simulations

Bipolar configuration with pole to ground fault or symmetric monopole with pole-to-pole fault

Several fault scenario simulated, issued from WP 4.3 (Deliverable D4.3)

Fault clearing speed (primary sequence)

KPI	Fault clearing strategy			
	Non-selective with AC CB	Non-selective with Converter Breaker (mechanical)	Non-selective with FB Converter (40kV CB & HSS)	Fully-Selective with hybrid breaker
Fault interruption time (ms)	1100	25	45	10

Potential impact on AC system stability

KPI	Fault clearing strategy			
	Non-selective with AC CB	Non-selective with Converter Breaker (mechanical)	Non-selective with FB Converter (40kV CB & HSS)	Fully-Selective with hybrid breaker
Active power restoration time (ms)	1600	150	110	[70 – 220]

Highly dependent on MMC control performances
Can be improved

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Some feedbacks regarding Cost / Performances Analysis of protection systems

System level protection requirements

Protection system performances (Acceptable KPIs)

At the right cost

Need for adequate assessment methodology (and tools)

Need for good DC CB cost models

Full selective fault clearing strategies with hybrid DC CB

- Seem to have higher performances but rely on MMC control performances
- About twice the cost of non selective converter breaker fault clearing strategy

Nonselective fault clearing strategies

- Lower performances, but most of the time acceptable from AC side requirements
- Could have limited application for very large high power DC grids
- Significant reduction of cost with converter breaker fault clearing strategy

Some perspectives regarding Cost / Performances Analysis of protection systems

Implementation of partially selective fault clearing strategies could be a good tradeoff to get acceptable KPIs at best cost

Develop the methodology for onshore DC grids containing mainly OHL

- Adaptation of KPIs with a different behavior: more frequent fault events to be managed: New KPIs?
- The contribution of protection system to total cost should be higher

Develop a comprehensive risk analysis methodology considering event, severity of events (in relation with KPIs) and probability of events

Opportunities to reduce DC CB cost are welcome

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