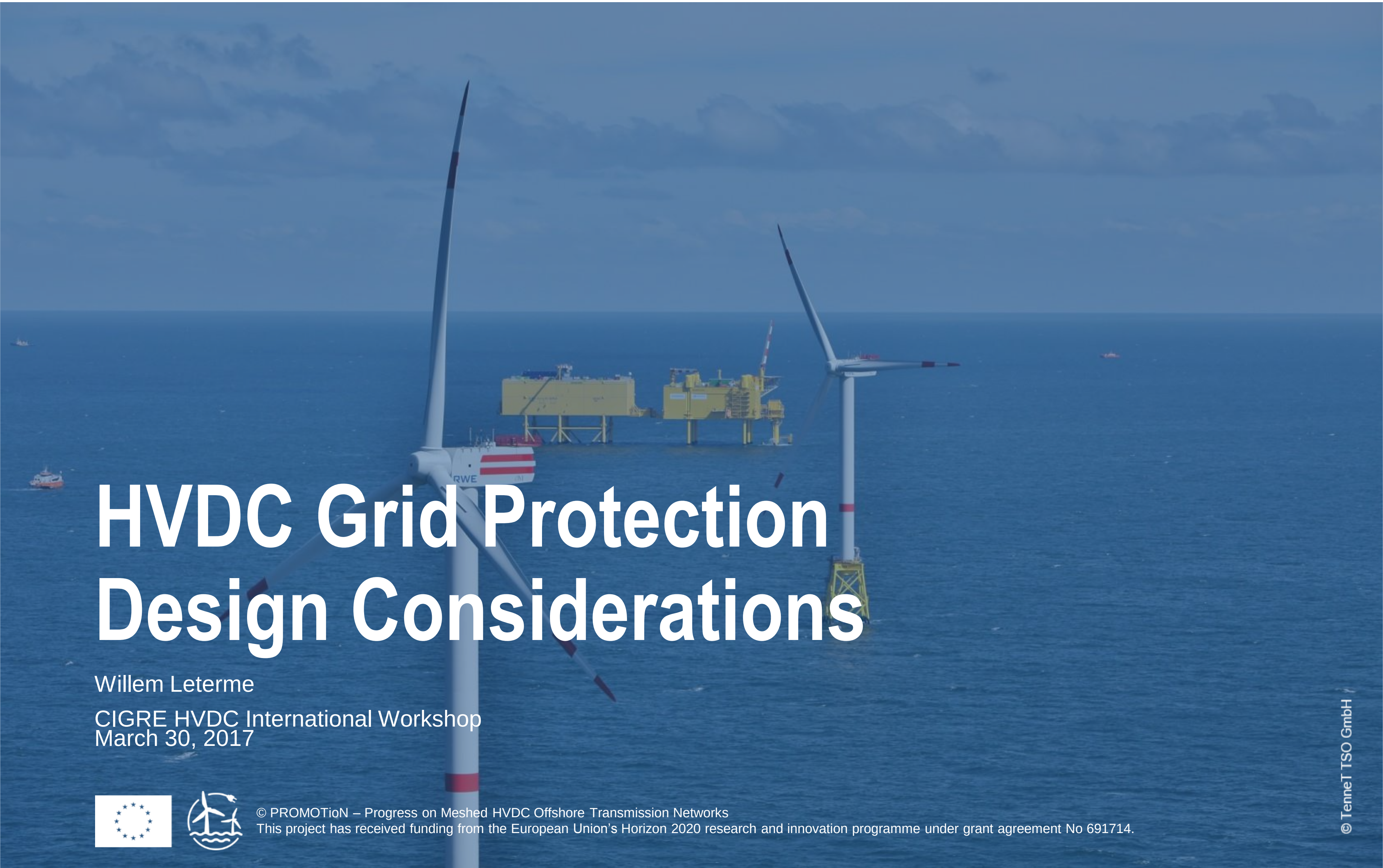
PROMOTioN
PROGRESS ON MESHED HVDC OFFSHORE TRANSMISSION NETWORKS



HVDC Grid Protection Design Considerations

Willem Leterme

CIGRE HVDC International Workshop
March 30, 2017

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

Protection design is trade-off between cost and desired reliability

- Minimize fault impact on the system operation
- Minimize stresses to components
- Ensure human safety
- What is the optimum for HVDC grid protection?

VSC HVDC: from point-to-point to multi-terminal and grids

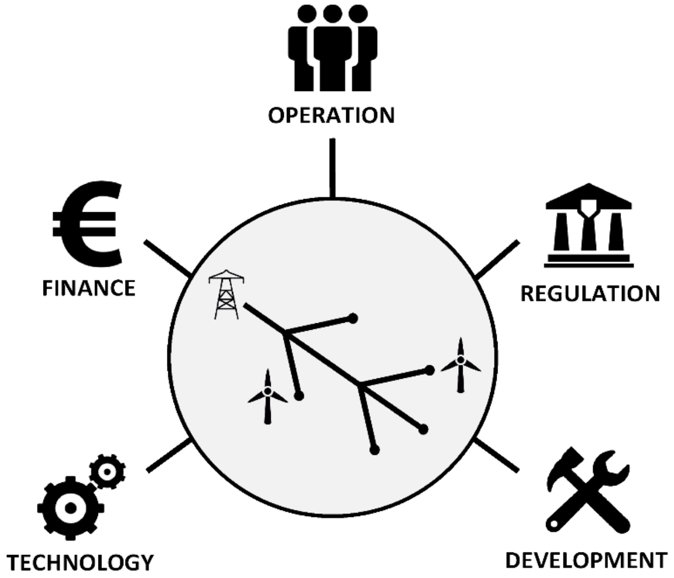
- VSC HVDC technology has matured for point-to-point links
  - Voltages have increased towards +-300 and +-500 kV

- First multi-terminal schemes have been built in China recently and are considered within Europe
  - Mainly as extension to the AC system, protected as “1” in N-1

- HVDC grids are considered as a fundamental upgrade for the existing AC system
  - Large grids can no longer be considered as “1”
  - Several challenges to be addressed => ProMOTION

Promotion project overview

- Cost effective and reliable converter technology
- **Grid protection**
- Financial framework for infrastructure development
- Regulation for deployment and operation
- Agreement between manufacturers, developers and operators of the grid



PROMOTioN WP 4 looks into different options for HVDC grid protection

PROMOTioN
PROGRESS ON MESHED HVDC OFFSHORE TRANSMISSION NETWORKS

- Develop functional requirements for HVDC grid protection for various grids
- Benchmark different fault clearing strategies
- Analyze selected fault clearing strategies in off- and on-line simulations
- Development of multi-purpose protection IEDS
- Investigate influencing parameters of protection in cost-benefit analysis

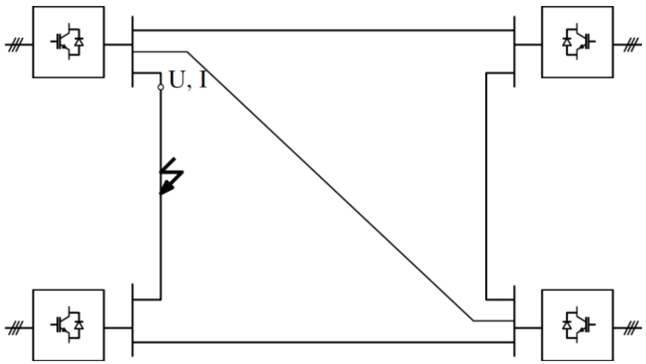
Presentation outline

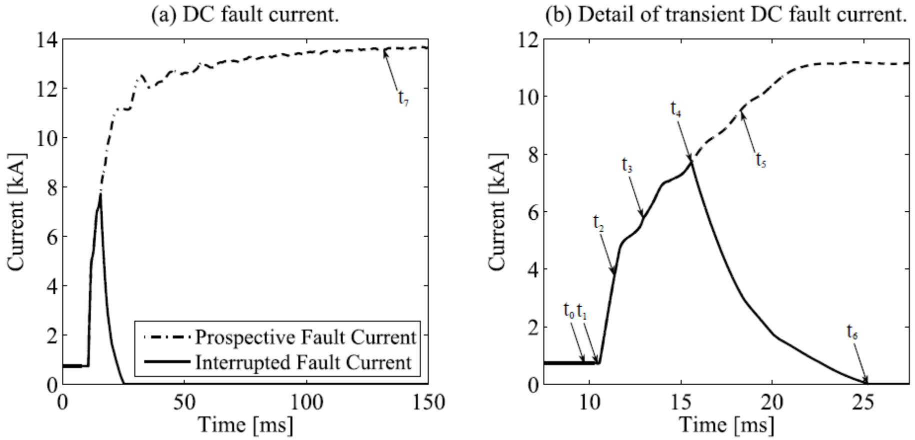
- Fault clearing strategies in HVDC grids
- Constraints for protection operation
- Trade-offs in HVDC grid protection design

Presentation outline

- **Fault clearing strategies in HVDC grids**
- Constraints for protection operation
- Trade-offs in HVDC grid protection design

Fault currents within a DC grid: example pole-to-pole fault

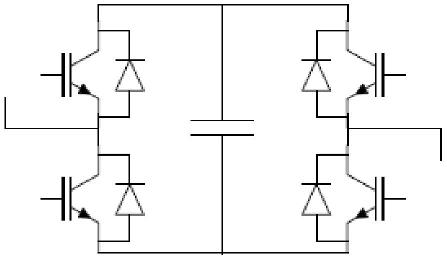




- Fault current:
  - No zero crossings
  - High rate-of-rise
  - High steady-state value

Different technologies exist to interrupt a DC fault current

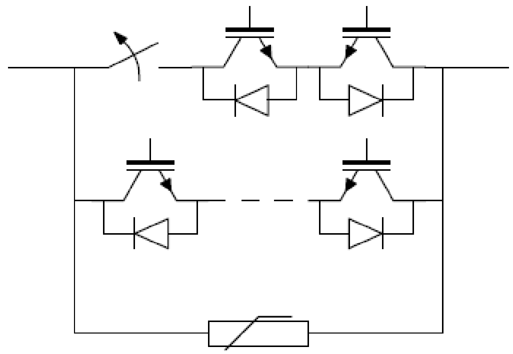
- Converter ac breakers
  - As used in existing projects
  - No additional cost
  - Slow (40-60 ms opening time)



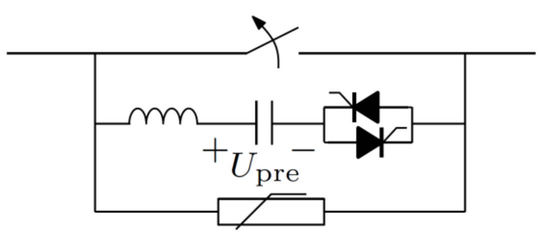
- Fault-current blocking converters
  - Full-bridge (commercially available)
  - Other concepts also exist
  - Higher losses compared with half-bridge
  - Fast (response within few ms)

Different technologies exist to interrupt a DC fault current

- DC Circuit Breakers

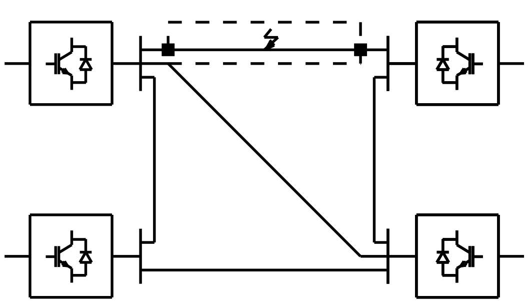


- Hybrid HVDC breakers
  - Prototypes tested
  - Power electronic component within main path generates losses
  - Operation times of 2-3 ms

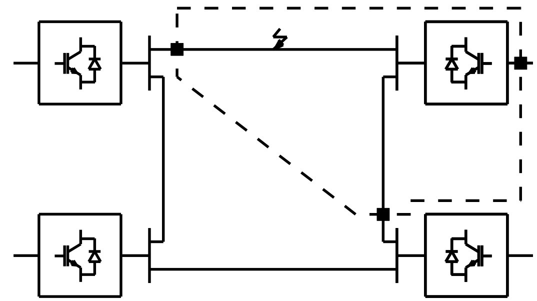


- Active resonant DC breakers
  - Prototypes tested
  - No power electronic components in main path
  - Operation times of 5-10 ms

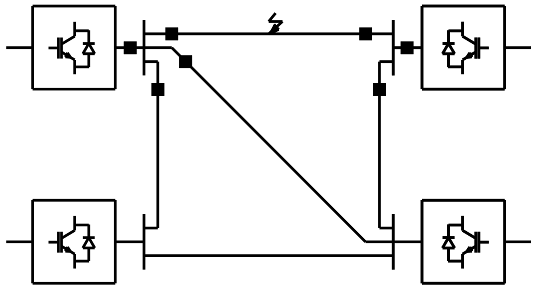
The use of different technologies leads to various fault clearing strategies



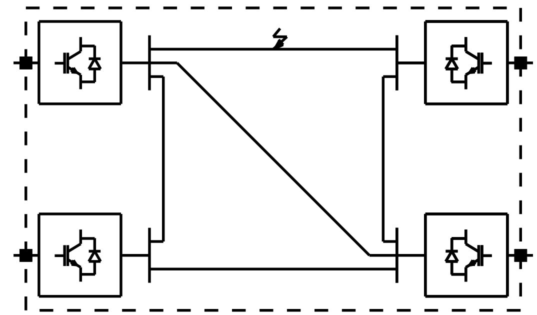
Selective (a,b): using
DC breakers in every line



Partially selective (d): split
DC grid in sub-grids



Open Grid (c):
alternative breaker
sequence



Non-selective (e):
shut down the
whole DC grid

Presentation outline

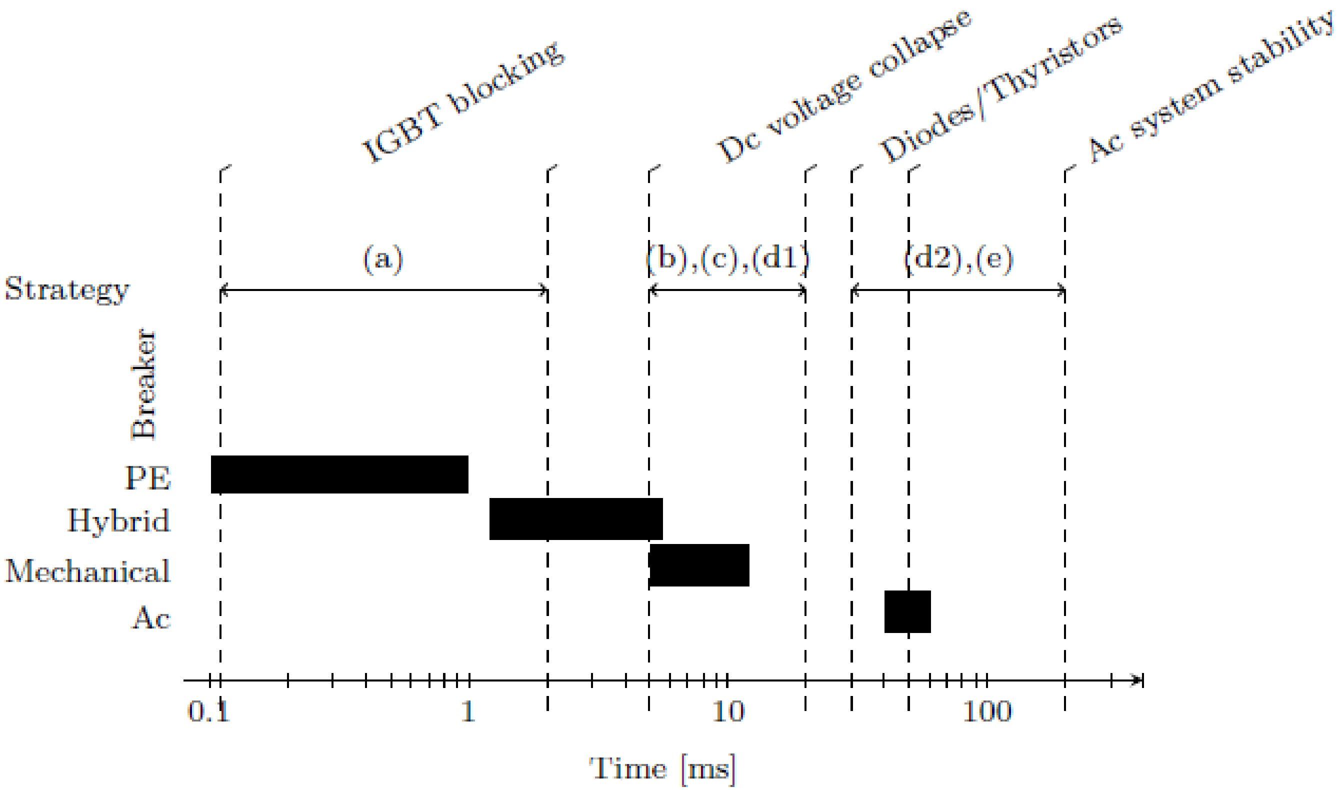
- Fault clearing strategies in HVDC grids
- **Constraints for protection operation**
- Trade-offs in HVDC grid protection design

Constraints are imposed at either the AC side or the DC side

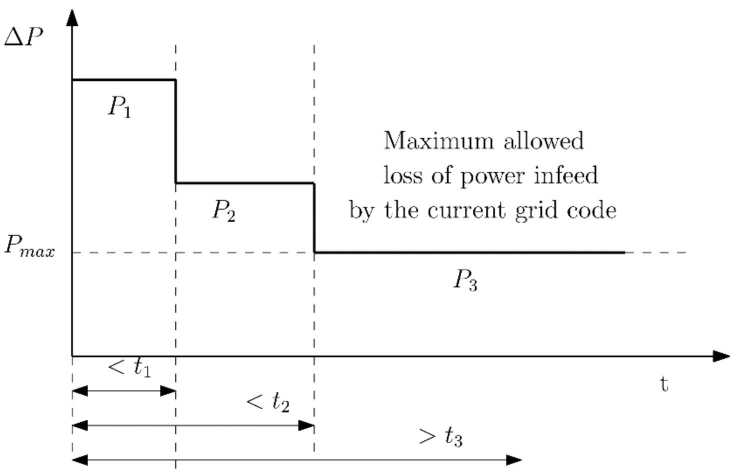
- DC side constraints
  - Component limits
    - IGBT Safe Operating Area (converters, breakers)
    - Thyristor limiting load integral (i^2t)
    - Breaker energy absorption capability
    - …
  - System limits
    - Ensure a stable DC voltage

- AC side constraints
  - System limits
    - Limit loss of infeed towards AC system
    - Transient stability issues

Strategies focusing on protecting the DC side must be an order of magnitude faster compared with those focusing on the AC side



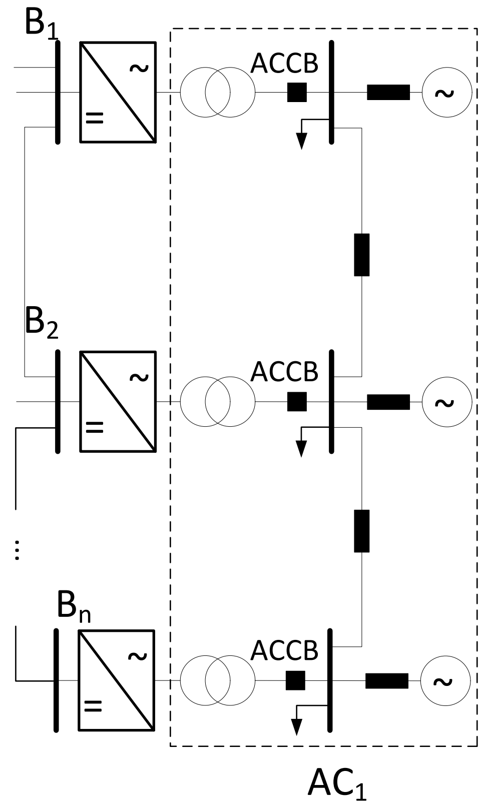
Additional AC side constraints might be imposed in future AC grid codes



- Current AC grid code:
  - Only defines maximum allowed permanent loss
  - E.g. Continental Europe: 3000 MW
- Possible future AC grid code:
  - Transient loss P_1: < t_1 (e.g. one cycle)
  - Temporary loss P_2: < t_2 (e.g. hundreds ms)
  - Permanent loss P_3

Possible future AC grid code lead to minimum requirements on DC grid protection

- Non-selective (AC circuit breaker)
  - Permanent loss $\sum_{i=1}^{n} PCi < P_3$
- Non-selective (converter with fault blocking capability)
  - Temporary loss $\sum_{i=1}^{n} PCi < P_2$
- Partially selective
  - Permanent loss $\sum_{i=1}^{l} PCi < P_3,\ l < n$
  - Temporary loss $\sum_{i=1}^{l} PCi < P_2, l < n$
- Fully selective (DC circuit breaker)
  - Transient loss $\sum_{i=1}^{n} PCi < P_1$



M. Abedrabbo, M. Wang, P. Tielens, F. Dejene, W. Leterme, J. Beerten, D. Van Hertem, “Impact of DC grid contingencies on AC system stability”, Proc. IET ACDC 2017, Birmingham, Manchester

Presentation outline

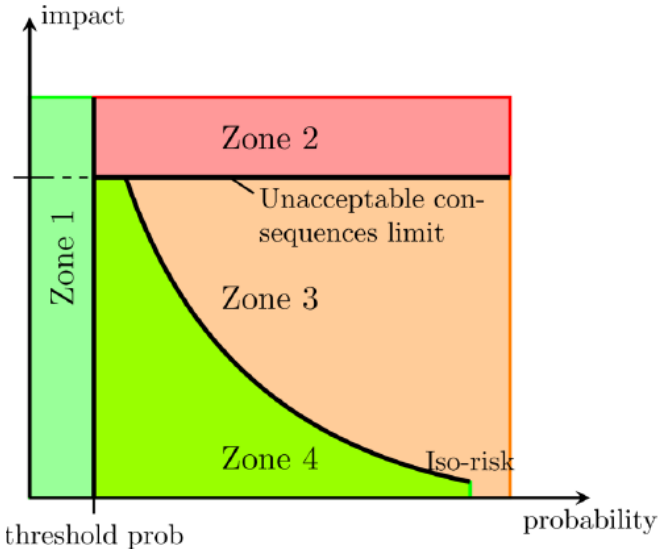
- Fault clearing strategies in HVDC grids
- Constraints for protection operation
- **Trade-offs in HVDC grid protection design**

Different types of faults require different countermeasures

Fault type	Line type	Probability	Symmetric monopole (high impedance ground)	Bipole (low impedance ground)
Pole-to-ground	Overhead line	+++	Overvoltage	Overcurrent
Pole-to-pole	Overhead line	++	Overcurrent	Overcurrent
Pole-to-ground	Cable	+	Overvoltage	Overcurrent
Pole-to-pole	Cable	---	Overcurrent	Overcurrent

- Depends on type of transmission line
- Depends on type of fault and grounding
- Depends on probability of occurrence

Desired impact decides which action to take



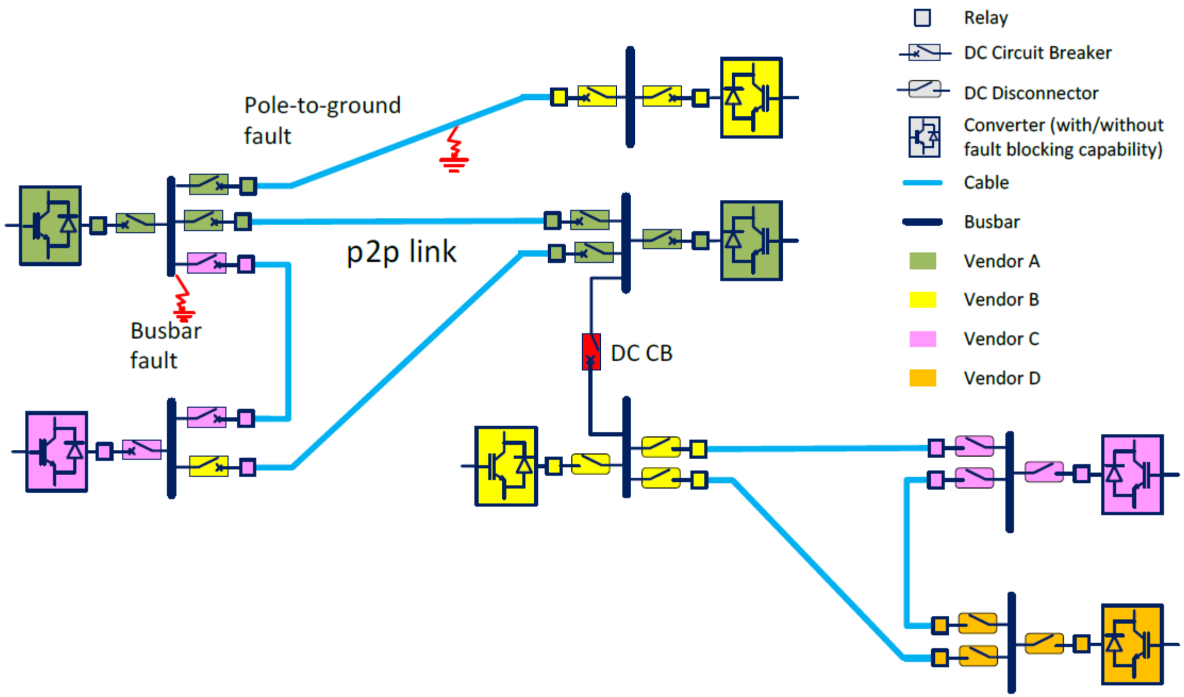
- Zone 1: out of norm
  - Highly unlikely
  - No particular protection design to address them
- Zone 2: unacceptable consequences
  - High impact, high probability
  - Reduce probability or impact (e.g., by adapting system design or protections)
- Zone 3: unacceptable risk
  - Medium impact, med-high probability
  - Adapting protections needed
- Zone 4: acceptable risk
  - Low impact, med-high probability
  - No actions necessary

Desired impact also influences the ratings of protective components

Fault type	Line type	Probability	Symmetric monopole (high impedance ground)	Bipole (low impedance ground)
Pole-to-ground	Overhead line	+++	Overvoltage	Overcurrent
Pole-to-pole	Overhead line	++	Overcurrent	Overcurrent
Pole-to-ground	Cable	+	Overvoltage	Overcurrent
Pole-to-pole	Cable	---	Overcurrent	Overcurrent

- Cable systems: limited currents if pole-to-ground faults are considered in symmetric monopole
  - Might result in lower breaking capabilities
  - Might be combined with slower protection
    - Cost reduction in protection
  - Higher voltages in the system
  - Pole-to-pole faults require shut-down of the entire system

Multi-vendor interoperability requires transition from project-specific design towards generic protection concepts



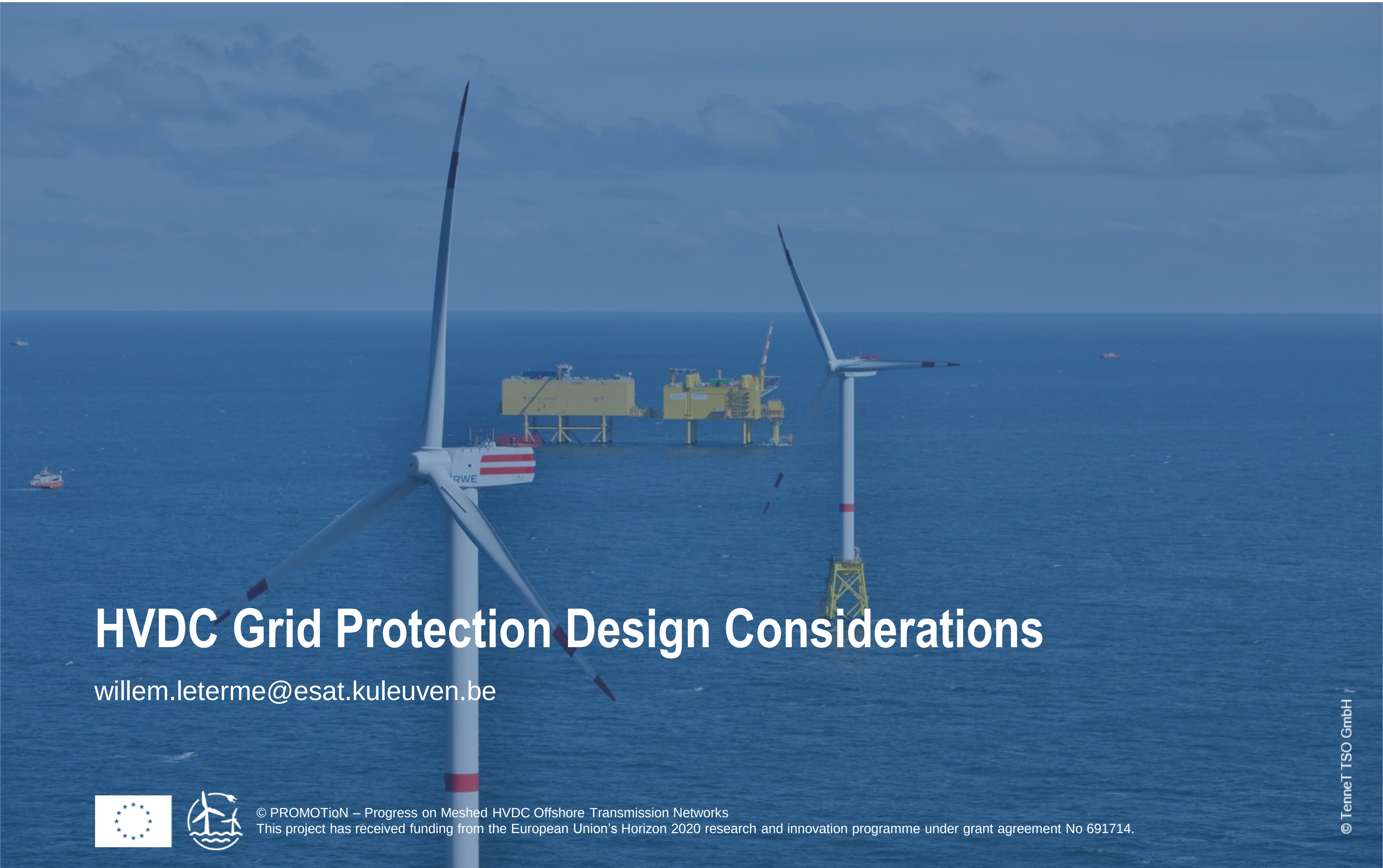
- Standardization needed
  - Converter control and protection during/post-fault
  - Breaker classes (operation time, current interruption capability)
  - Current/overvoltage levels in the system
  - Relay inputs/outputs

Summary

- Fault clearing strategies in HVDC grids
  - Different options exist depending on technology and objective of protection
- Constraints for protection operation
  - Protecting the DC side itself requires much faster actions compared with protecting the AC side
- Trade-offs in HVDC grid protection design
  - Fault type and impact determine required protection and components
  - Multi-vendor interoperability must be considered

HVDC Grid Protection Design Considerations

willem.leterme@esat.kuleuven.be



© TenneT TSO GmbH

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

APPENDIX

DISCLAIMER & PARTNERS

COPYRIGHT

PROJECT COORDINATOR

DNV GL, Kema Nederland BV
Utrechtseweg 310, 6812 AR Arnhem, The Netherlands
Tel +31 26 3 56 9111
Web www.dnvgl.com/energy

CONTACT

willem.leterme@esat.kuleuven.be

PARTNERS

DNV GL (Kema Nederland BV), ABB AB, KU Leuven, KTH Royal Institute of Technology, EirGrid plc, SuperGrid Institute, Deutsche WindGuard GmbH, Mitsubishi Electric Europe B.V., Affärsverket Svenska kraftnät, Alstom Grid UK Ltd (Trading as GE Grid Solutions), University of Aberdeen, Réseau de Transport d'Électricité, Technische Universiteit Delft, Statoil ASA, TenneT TSO B.V., Stiftung OFFSHORE-WINDENERGIE, Siemens AG, Danmarks Tekniske Universitet, Rheinisch-Westfälische Technische Hochschule Aachen, Universitat Politècnica de València, Forschungsgemeinschaft für. Elektrische Anlagen und Stromwirtschaft e.V., Dong Energy Wind Power A/S, The Carbon Trust, Tractebel Engineering S.A., European University Institute, Iberdrola Renovables Energía, S.A., European Association of the Electricity Transmission & Distribution Equipment and Services Industry, University of Strathclyde, ADWEN Offshore, S.L., Prysmian, Rijksuniversiteit Groningen, MHI Vestas Offshore Wind AS, Energinet.dk, Scottish Hydro Electric Transmission plc