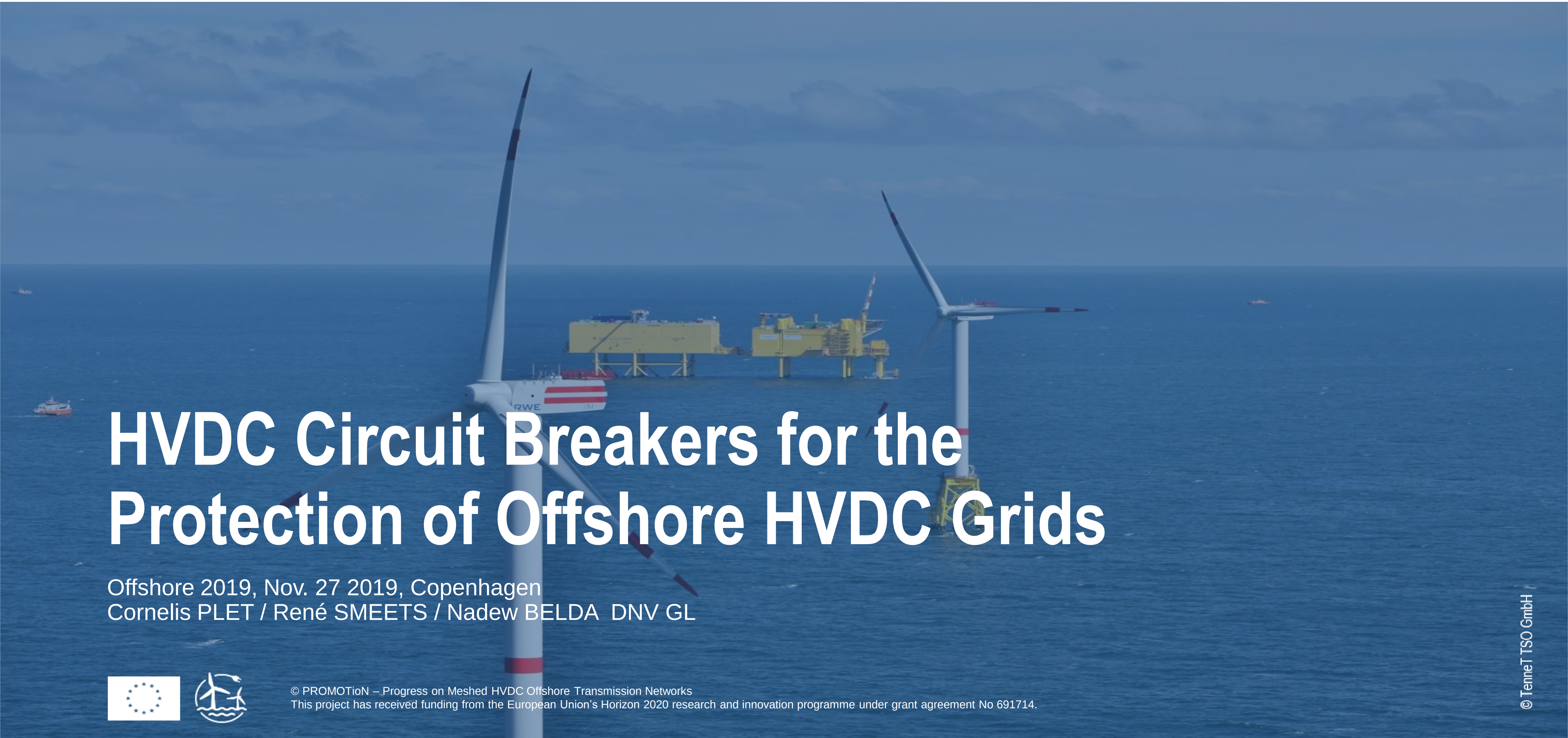
PROMOTioN
PROGRESS ON MESHED HVDC OFFSHORE TRANSMISSION NETWORKS

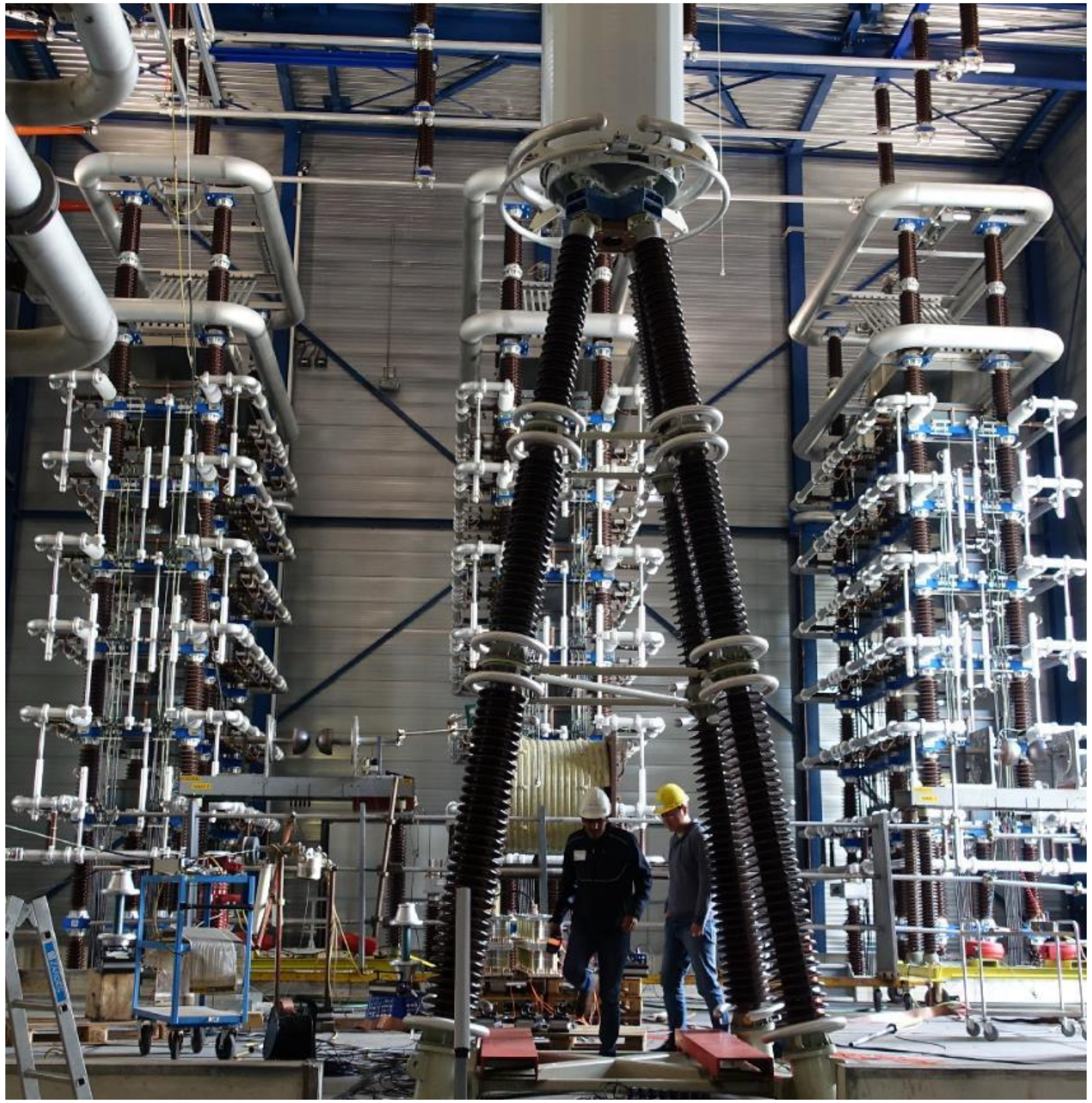


HVDC Circuit Breakers for the Protection of Offshore HVDC Grids

Offshore 2019, Nov. 27 2019, Copenhagen

Cornelis PLET / René SMEETS / Nadew BELDA DNV GL

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



PROMOTioN research work on HVDC breaker stresses @ KEMA labs

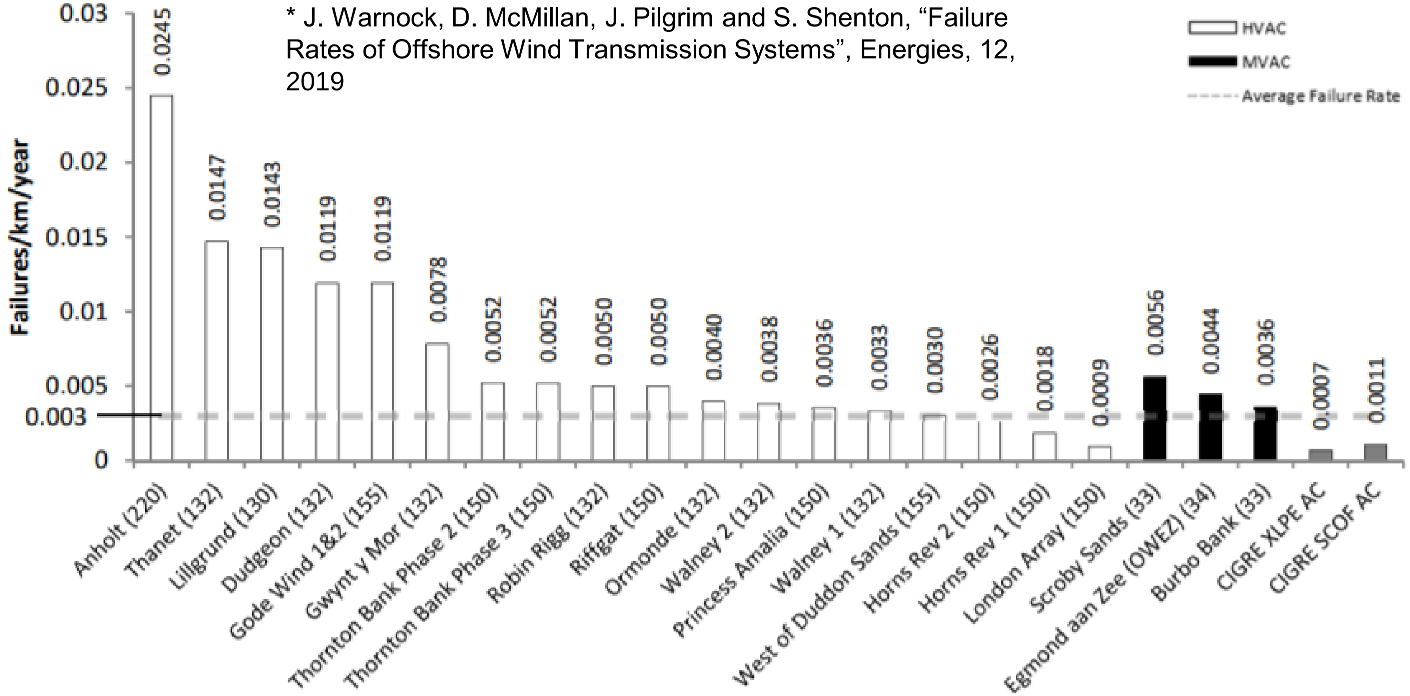
- Why breakers come in handy in DC grids?
- They do not exist yet. What‘s the issue?
- What technology can do it?
- What do they need to endure in service?
- What do their internal parts need to endure?
- How to prove that they work?

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

Submarine power cable faults do occur

- 70-80% of pay-outs from insurers to windfarm operators are related to cable faults**
- By 2030 10-40 large subsea cable repairs per year**
- Faults threaten system integrity

DC cable damage after boat anchoring (IEEE P&E, May 2019)



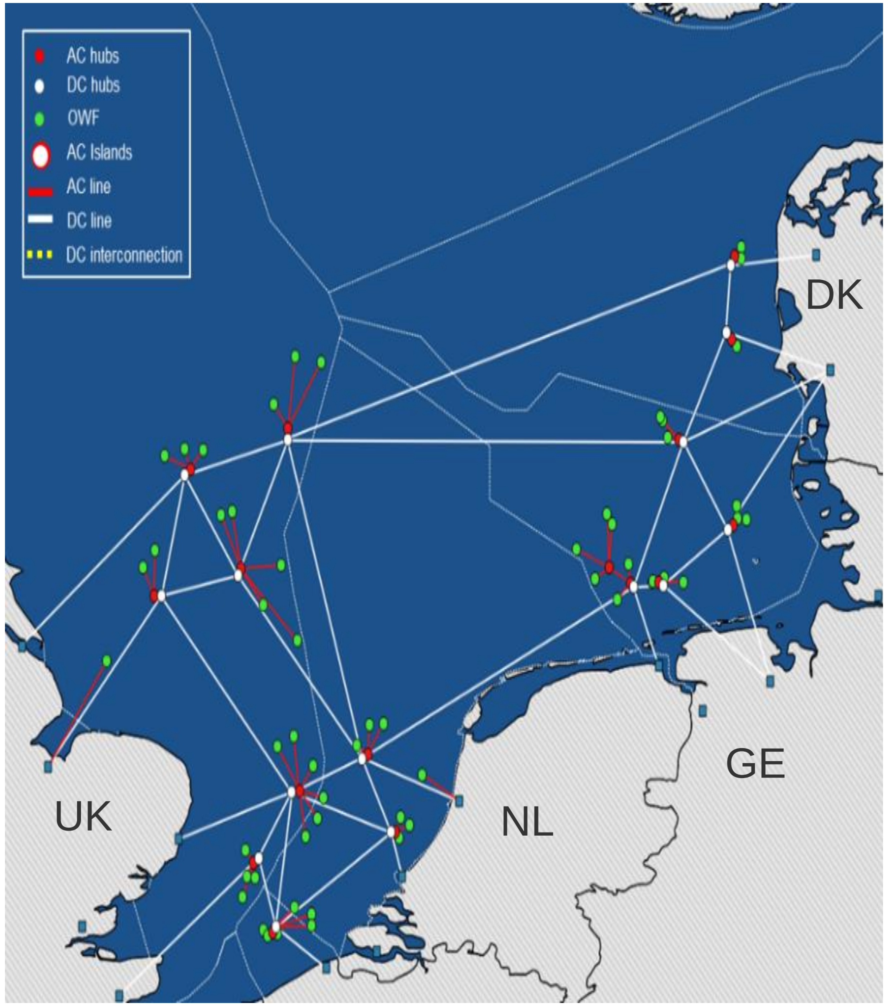
* J. Warnock, D. McMillan, J. Pilgrim and S. Shenton, “Failure Rates of Offshore Wind Transmission Systems”, Energies, 12, 2019

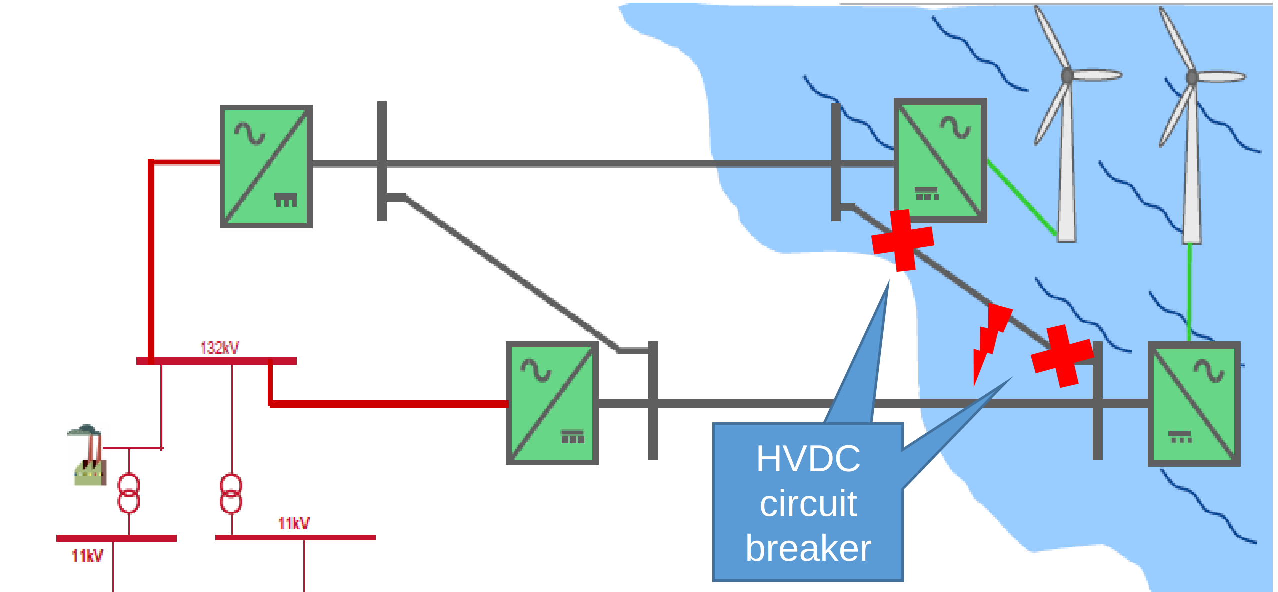
HVAC offshore cables: 3 faults per 1000 km per year*
HVDC offshore cables: 0.5 – 2.0 faults per 1000 km per year**

** M. Kurkowska, “Cable malfunctions”, Offshore Cabling, 2018

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

HVDC grids need selective de-energization of faulted branches





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

What these activities in PROMOTioN achieved

Situation before PROMOTioN

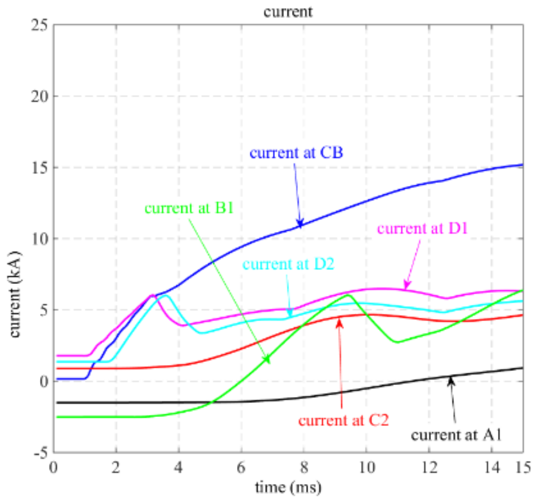
- Obstacle in the development of HVDC grids
- HVDC circuit breakers are only installed very recently in limited Chinese pilot projects
- Technology “Chinese only”
- No service experience available
- No international standards
- Requirements unknown
- Only limited functions tested (China)

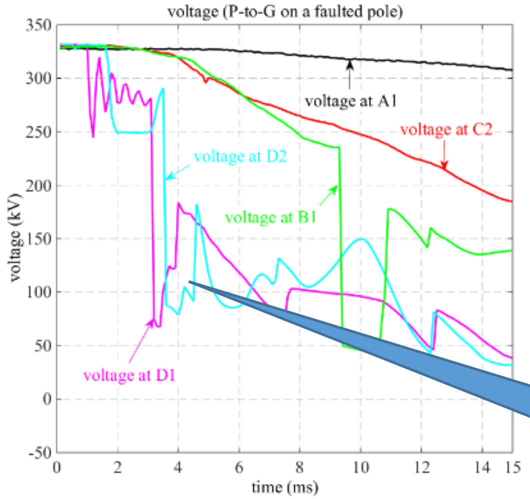
PROMOTioN’s contribution (WP5, 10)

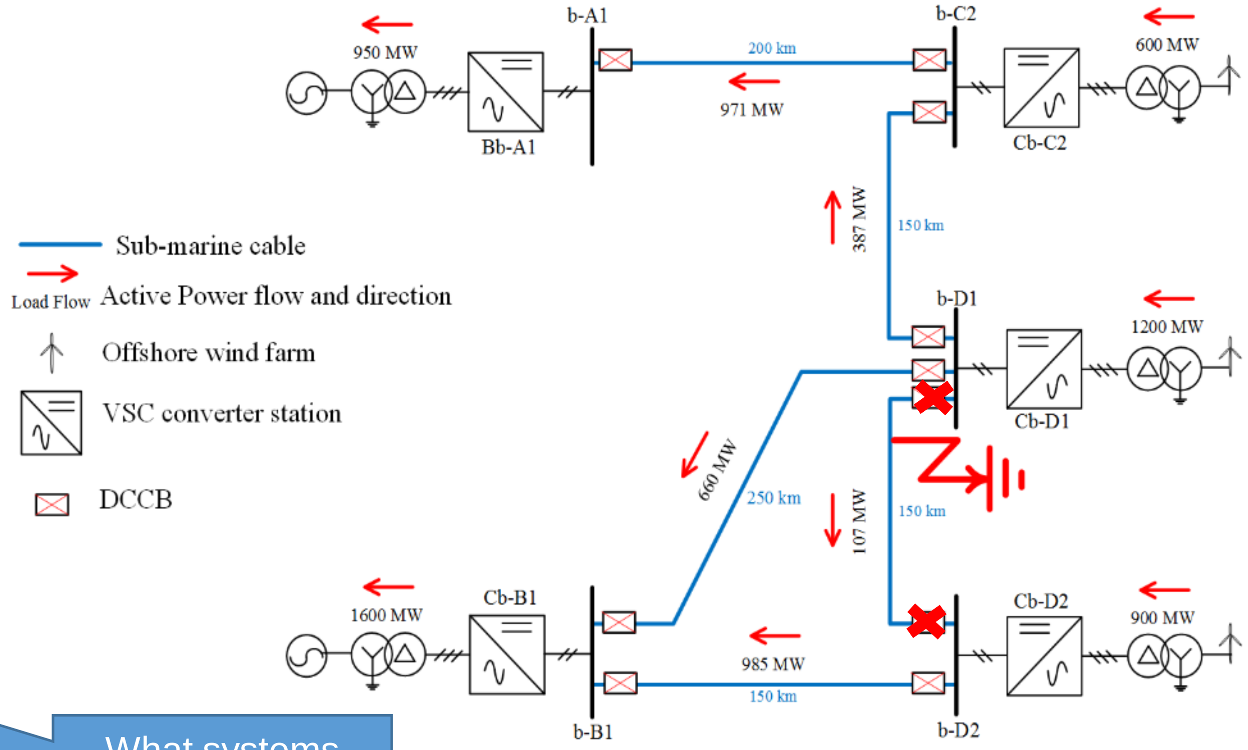
- Incentive to develop and test prototypes of 3 technologies; TRL to 6 -> 8
- HVDC breakers are key enablers of a North Seas HVDC grid
- European breaker technology demonstrated
- Test experience gathered and shared
- Initiation of standardization IEC, CIGRE
- Agreed a set of test-requirements
- Full-power one-shot test solution developed

Understanding stresses in systems that do not exist yet

- System simulation studies in order to understand electrical stresses on HVDC breakers during faults
- For definition of test-requirements / standards consider breaker as a black-box





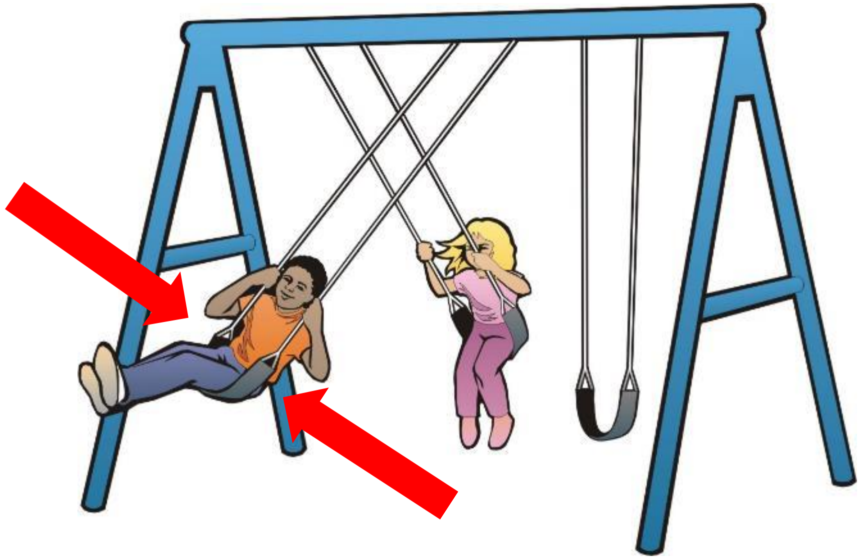


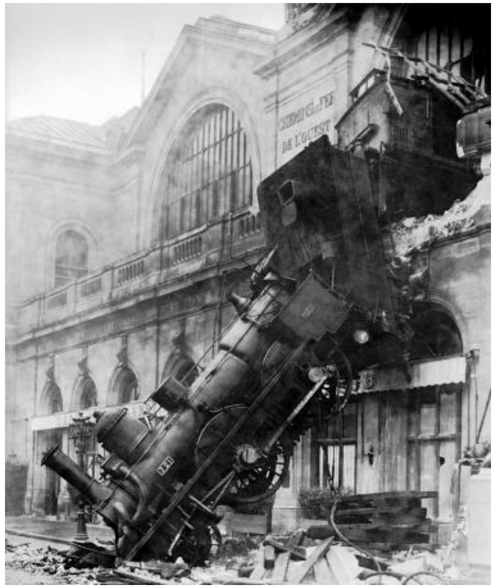
What systems face without HVDC breakers

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

DC current interruption: challenges

15 kA in 100 km line = 11 MJ
= 30 ton train at 100 km/h





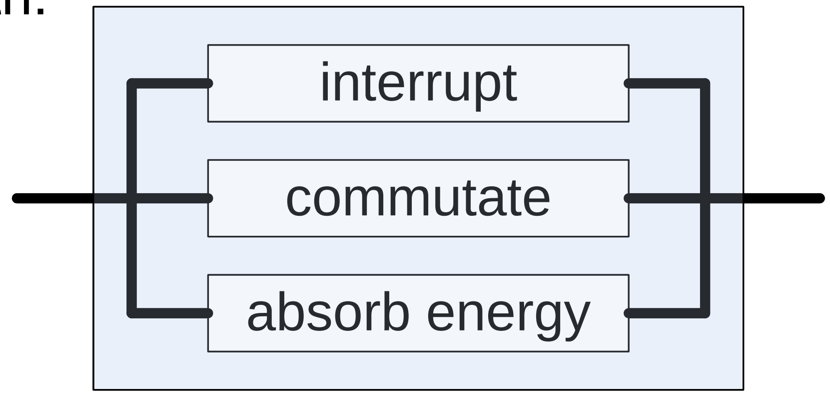
AC interruption:
Capture the swinging mass in its outer position:
Zero kinetic energy <-> AC current zero crossing

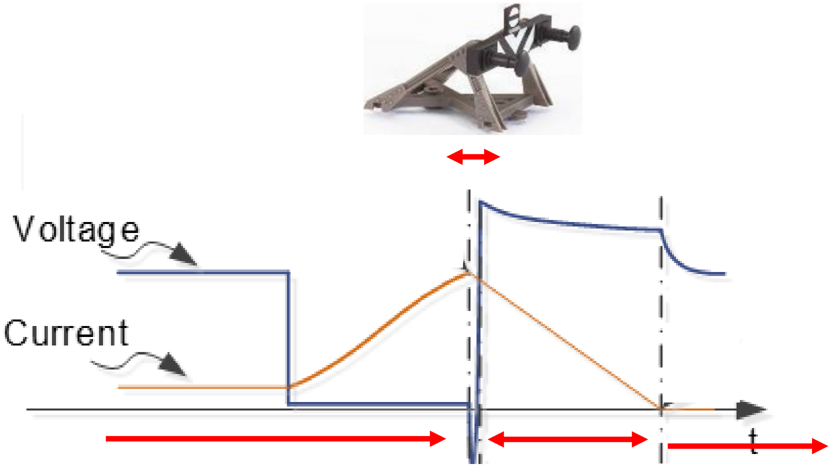
DC interruption:
Oppose the motion of a linearly moving mass by a buffer: **counter voltage**

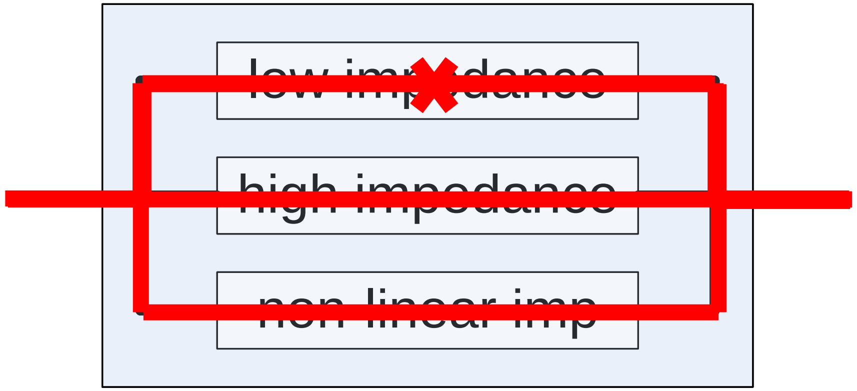
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691714.

Strategy to generate counter voltage: play with impedance

- Strategy:
  - Create a blockade ('current zero') for current in the main path: <u>interrupt</u>
  - Current must transfer into high-impedance path: <u>commutate and generate counter voltage</u>
  - Limit and sustain the counter voltage with energy absorber <u>absorb energy</u>

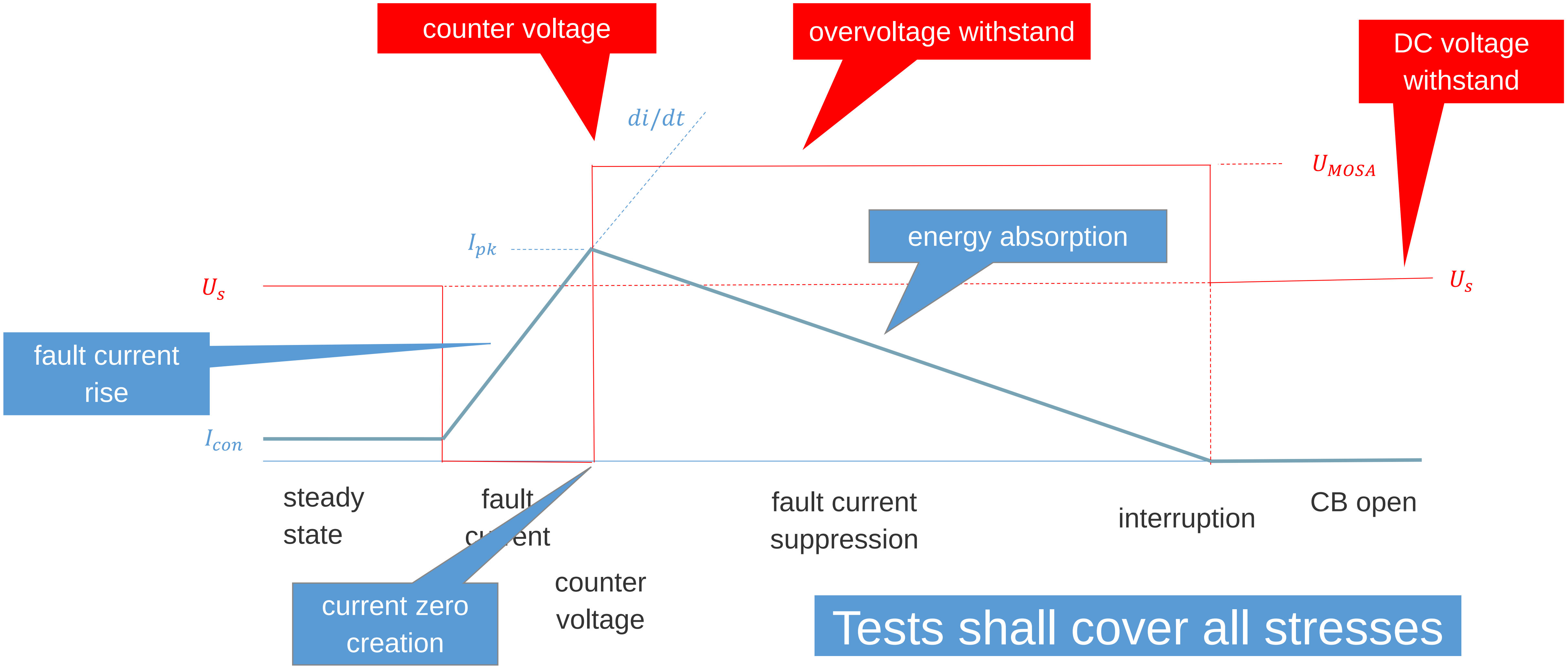






This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691714.

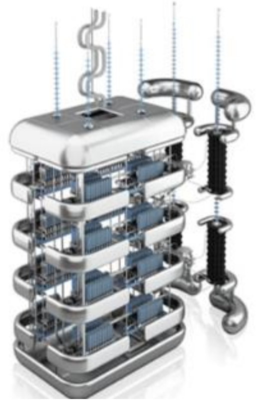
The six critical stages of HVDC fault current interruption



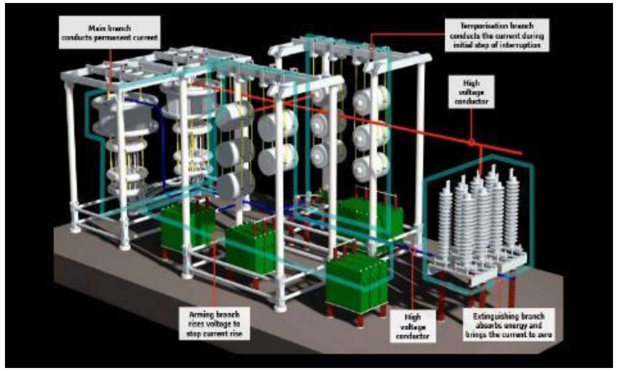
Tests shall cover all stresses

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

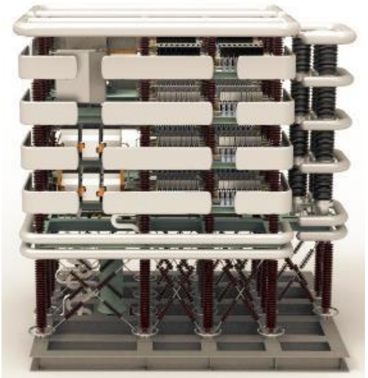
HVDC circuit breaker prototypes and pilots



Concept SE 2011

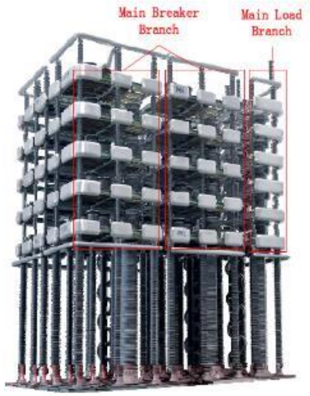


Concept thyristor based FR 2014



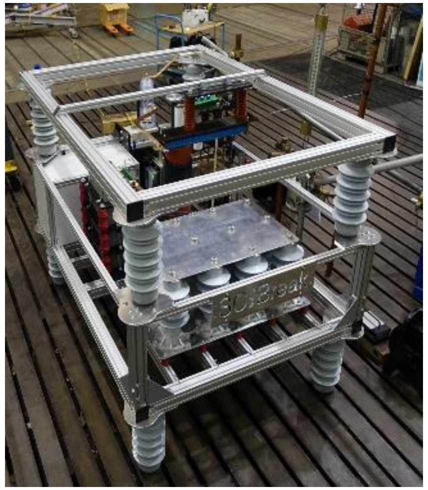
200 kV Zhoushan CN 2017

160 kV Nanao CN 2018



500 kV Zhangbei CN 2022

500 kV CN 2022

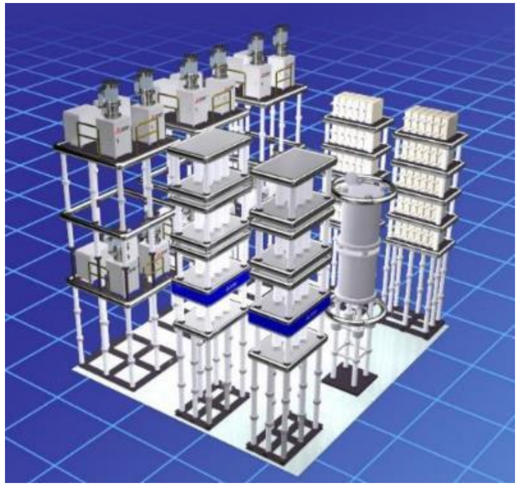


24 kV full-power test 2017 SE

160-200 kV full-power test 2019 JP

350 kV SE (2020-02 test)

80 kV SE (2020-04 test)

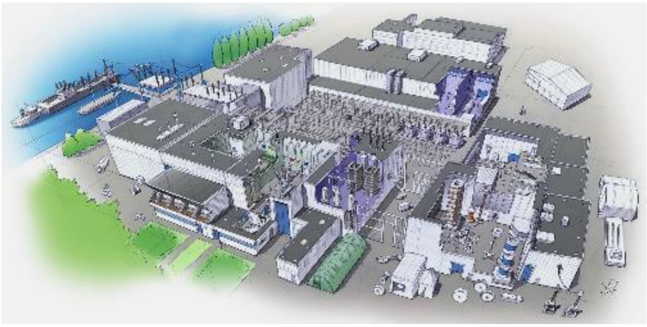


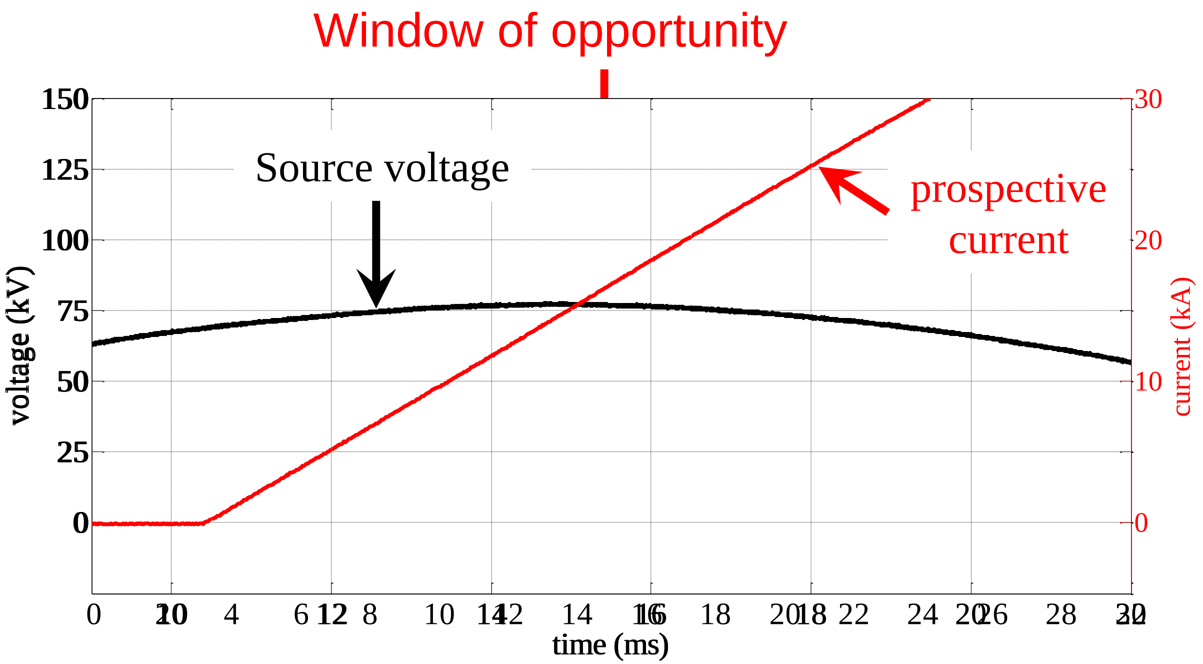
525 kV concept JP

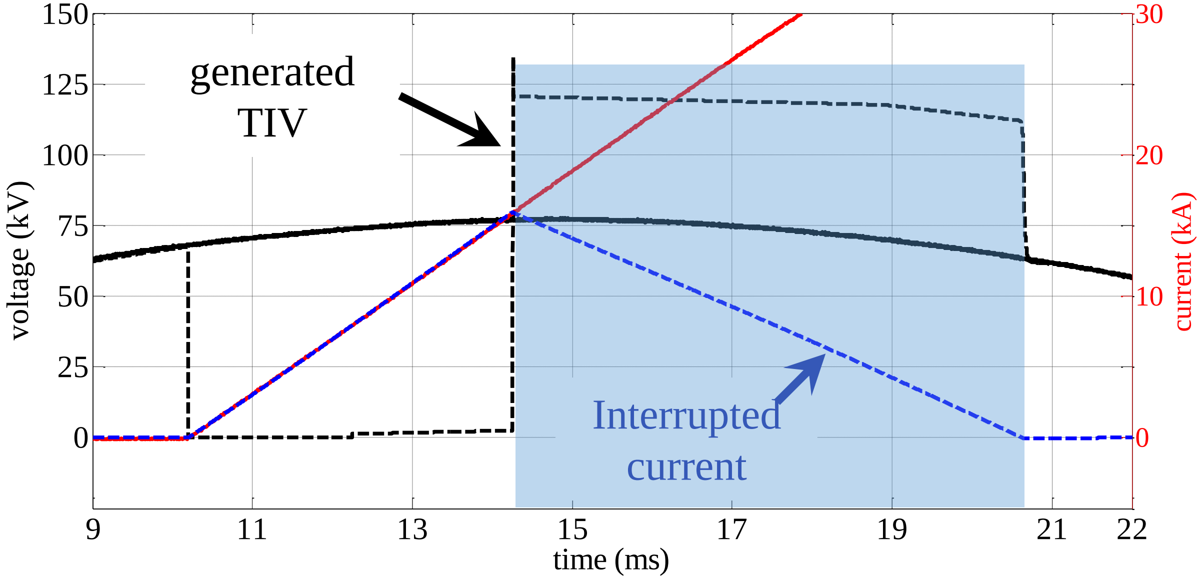
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691714.

Testing

- Multiple 16⅔ Hz AC power sources can mimic DC condition
- Adequate circuits supply correct stresses during all periods of interruption
- First time performance







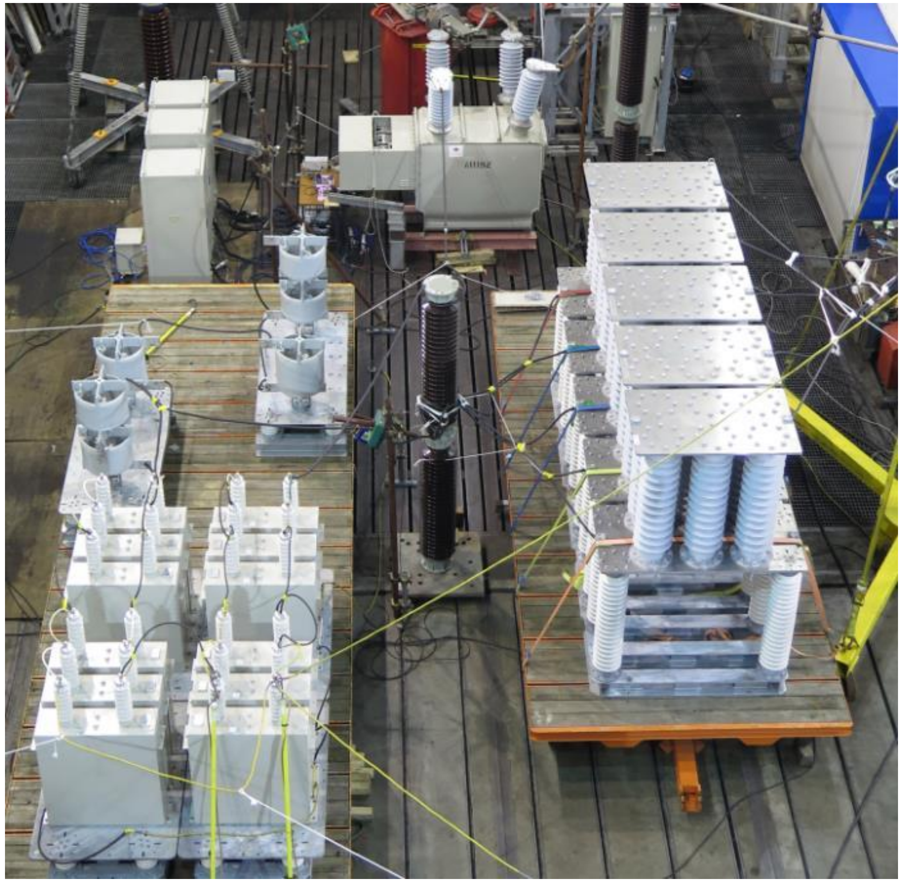
6 Short-circuit Generators

10 Step-up Transformers

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

Full-power testing of 160-200 kV active current injection breaker

Testing with low-frequency AC generators includes all relevant stresses during the fault clearing process

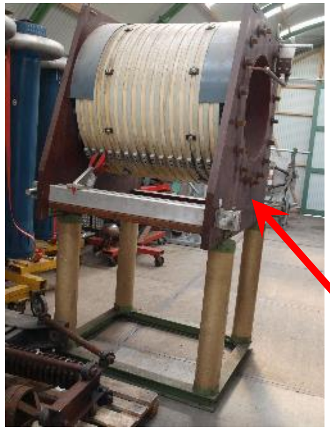


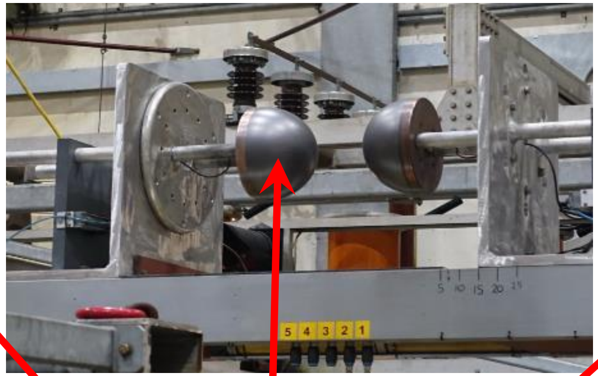
Single module 120 kV counter voltage

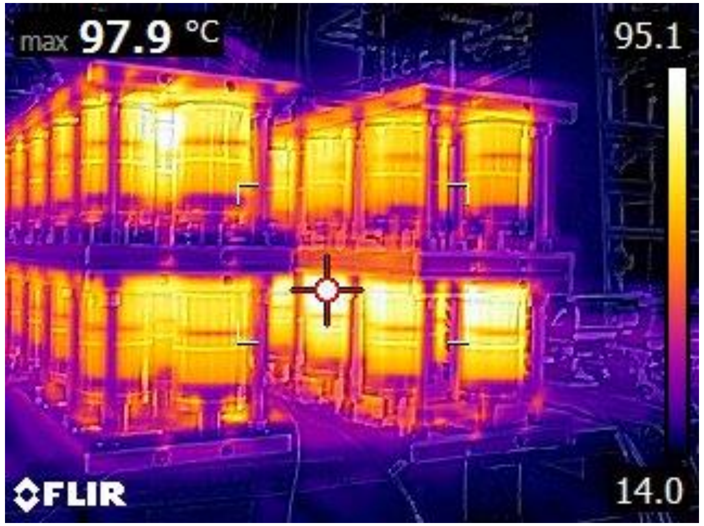
Demonstration test of double module 240 kV counter voltage

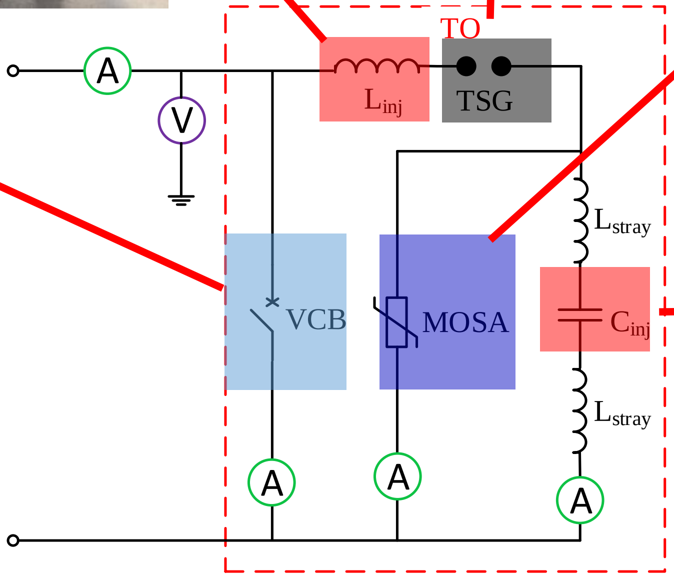
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691714.

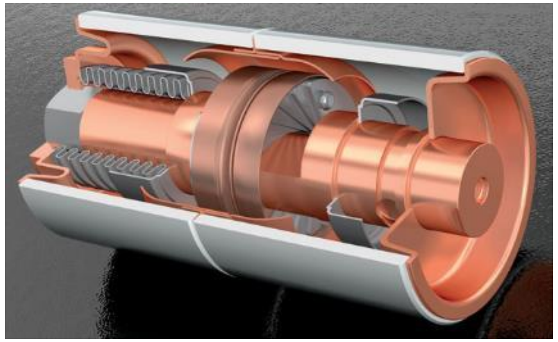
Getting to know the internal critical stresses by power experiments

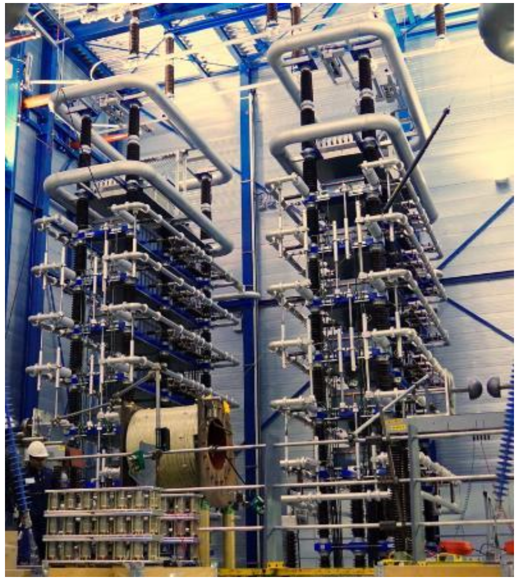










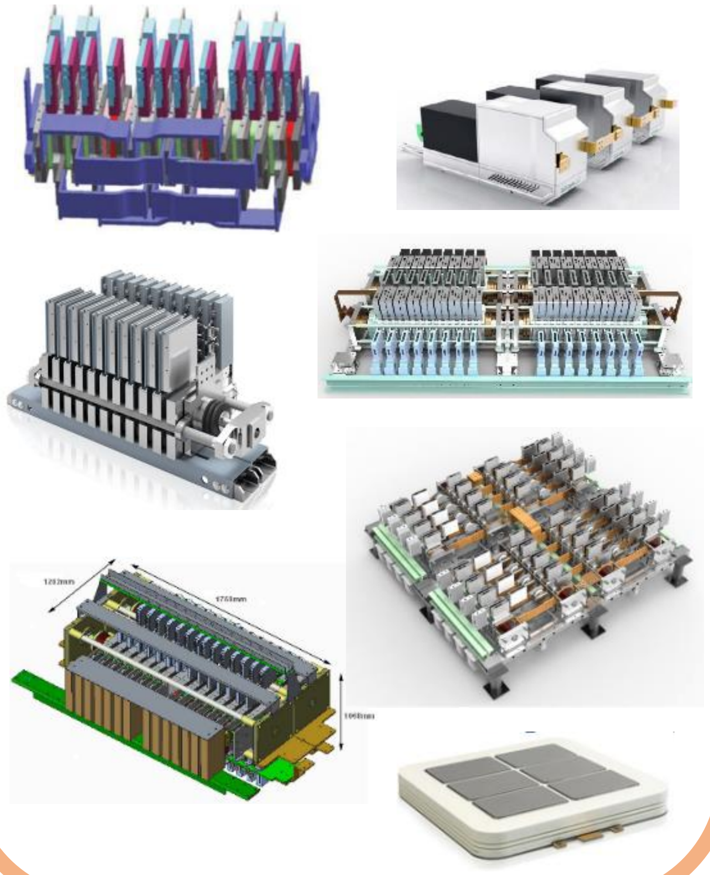


This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 691714.

Standard components used in a non-standard application

switching gaps and drives

semiconductor switches



metal oxide surge arresters

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

Potential issue: risk mitigation by defining proper requirements

subcomponent	normal operation	HVDC CB application	potential issue?
(Multiple) electrodynamic actuator(s) for mechanical switching device	Speed 1 – few m/s	Ultra-high speed, high impact force Electronics onboard	Mechanical reliability Compatibility with equipment attached (bellows of vacuum interrupters) EMI sensitivity
Power supply to actuator(s)	On earth potential	On high potential	Non-galvanic power supply
Vacuum interrupters for interruption	Power frequency AC current interruption	HF current and / or interruption, isolation at small gap length	HF current interruption
Vacuum interrupters for insulation	AC voltage insulation	DC voltage applied	DC voltage withstand capability
High-speed (vacuum, PE) making switches	Capacitor bank inrush current making	Injection current making above highest IEC standardized value	Contact welding
Multiple vacuum breakers in series	Not applied; vast majority of VCB is single break	Several / many in series	Grading for transients and DC Redundancy Mechanical synchronicity
SF6 gap(s) for insulation (ultra-fast disconnector)	Very low opening speed in GIS AC application	Ultra-high contact separation speed	Shall not switch any current Dynamic DC voltage withstand capability Mechanical consistency over time
Semiconductors in continuous current path (load commutation switch function)	Semiconductors switch with high frequency	Conduct continuously and switch only occasionally	Thermal stability
Semiconductors in commutation path (main breaker function)	Semiconductors switch with high frequency	Never conduct and switch only occasionally	Reliability after long idle time
MOSA consisting of multiple columns	Overvoltage protection	Significant energy absorption	Thermal overload Current sharing between columns
MOSA columns	Always under (AC) voltage	Occasionally stressed by voltage	Conditioning

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

Results

- HVDC breakers for HVDC grid protection are technically feasible and will have been demonstrated by the end of the project
- Three different technologies tested along industry agreed guidelines
- High-power AC short-circuit generators in low-frequency mode are used to verify all six critical stages of fault current interruption
- Test facility and publicly proven HVDC breaker technology now available in Europe
- Test- and research experiences are now being transferred to CIGRE and IEC by defining standards for testing HVDC circuit breakers

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

The opinions in this presentation are those of the author and do not commit in any way the European Commission

PROJECT COORDINATOR

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

CONTACT

rene.smeets@dnvgl.com

PARTNERS

DNV GL Netherlands B.V., 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, Equinor, TenneT TSO B.V., Stiftung OFFSHORE-WINDENERGIE, Siemens AG, Danmarks Tekniske Universitet, Rheinisch-Westfälische Technische Hochschule Aachen, Universitat Politècnica de València, SCiBreak AB, Forschungsgemeinschaft für. Elektrische Anlagen und Stromwirtschaft e.V., Ørsted Wind Power A/S, The Carbon Trust, Tractebel Engineering S.A., European University Institute, S.A., European Association of the Electricity Transmission & Distribution Equipment and Services Industry, University of Strathclyde, S.L., Prysmian, Rijksuniversiteit Groningen, MHI Vestas Offshore Wind AS, Energinet, Scottish Hydro Electric Transmission plc, SCiBreak AB