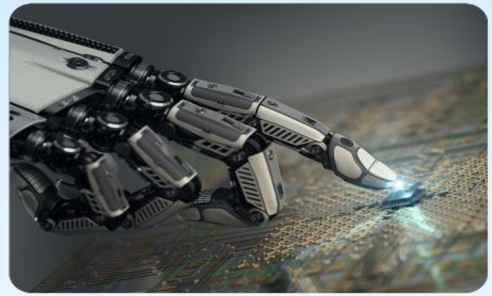
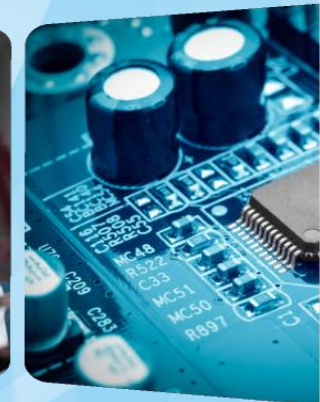






Progress On Meshed Offshore HVDC Transmission Networks

Cornelis Plet, DNV GL Energy

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

IEEE

Content

- PROMOTioN
- HVDC Circuit Breaker Testing
  - HVDC circuit breaker technology
  - Test circuit requirements
  - AC short-circuit generator based test circuit
  - Test results – mechanical circuit breaker with active current injection

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

European Commission energy strategy

By 2030.....

40%

cut in greenhouse gas emissions compared to 1990 levels

27%

share of renewable energy consumption

27%

energy savings compared with the business-as-usual scenario

15%

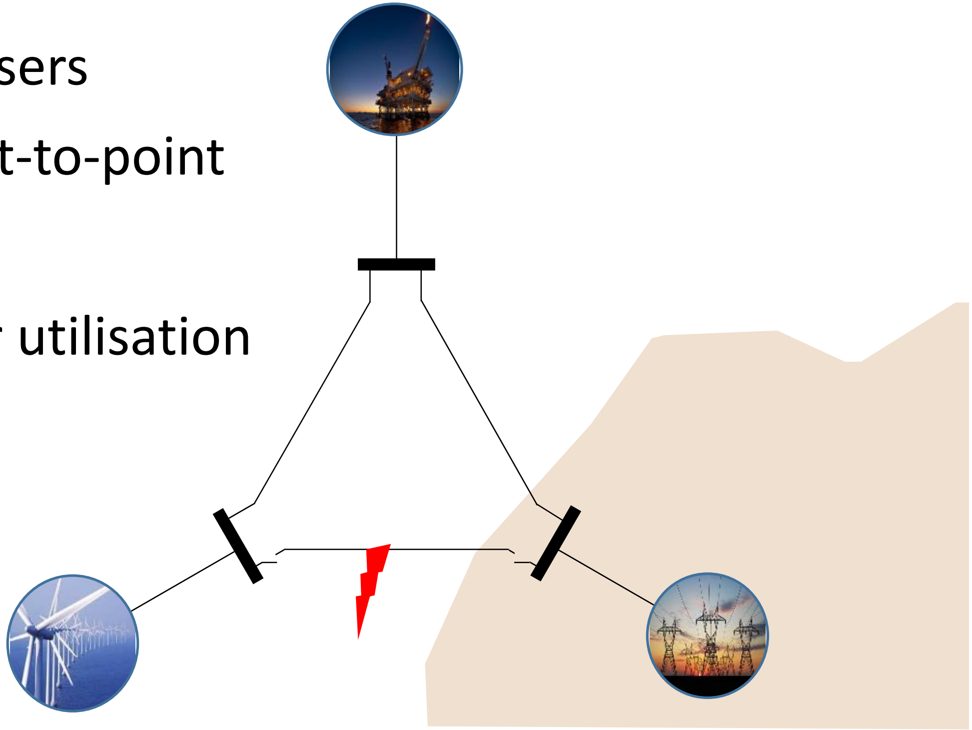
electricity interconnection target

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

Offshore meshed HVDC transmission network

Need

- Different types of offshore users
- Traditionally connected point-to-point
- Interconnector function
- Dedicated connection, lower utilisation
- Reliability offshore
- Mesh offers benefit

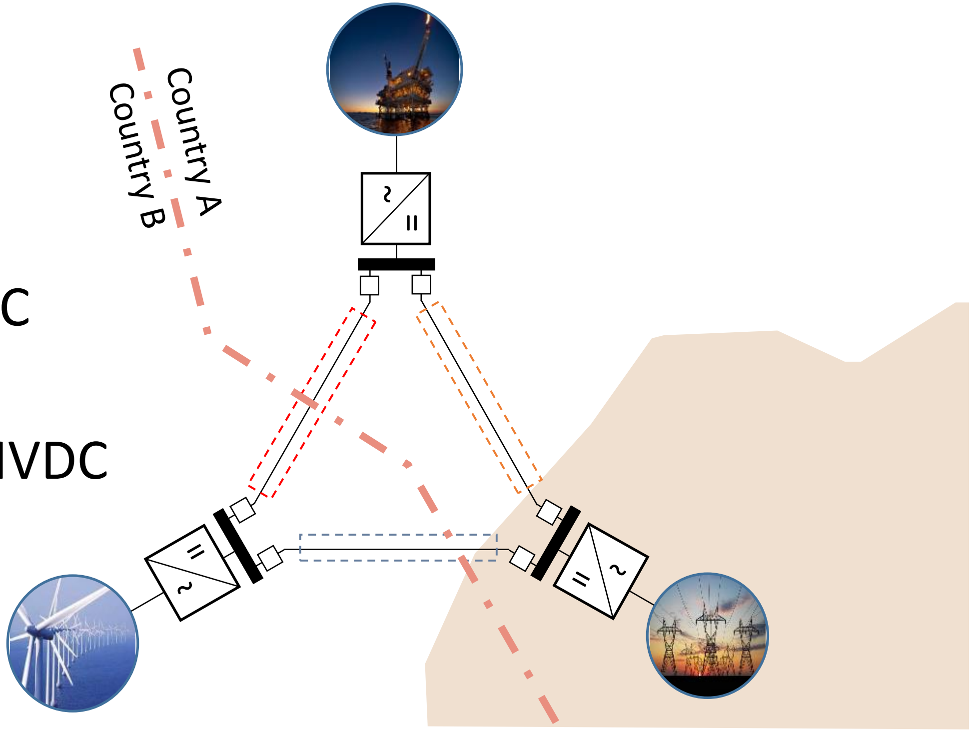


This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691714.

Offshore meshed HVDC transmission network

Challenges

- Offshore requires cables
- Long cables require HVDC
- HVDC requires converters
- HVDC network requires HVDC protection system
- Protection system requires HVDC switchgear / circuit breakers
- Transnational network



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

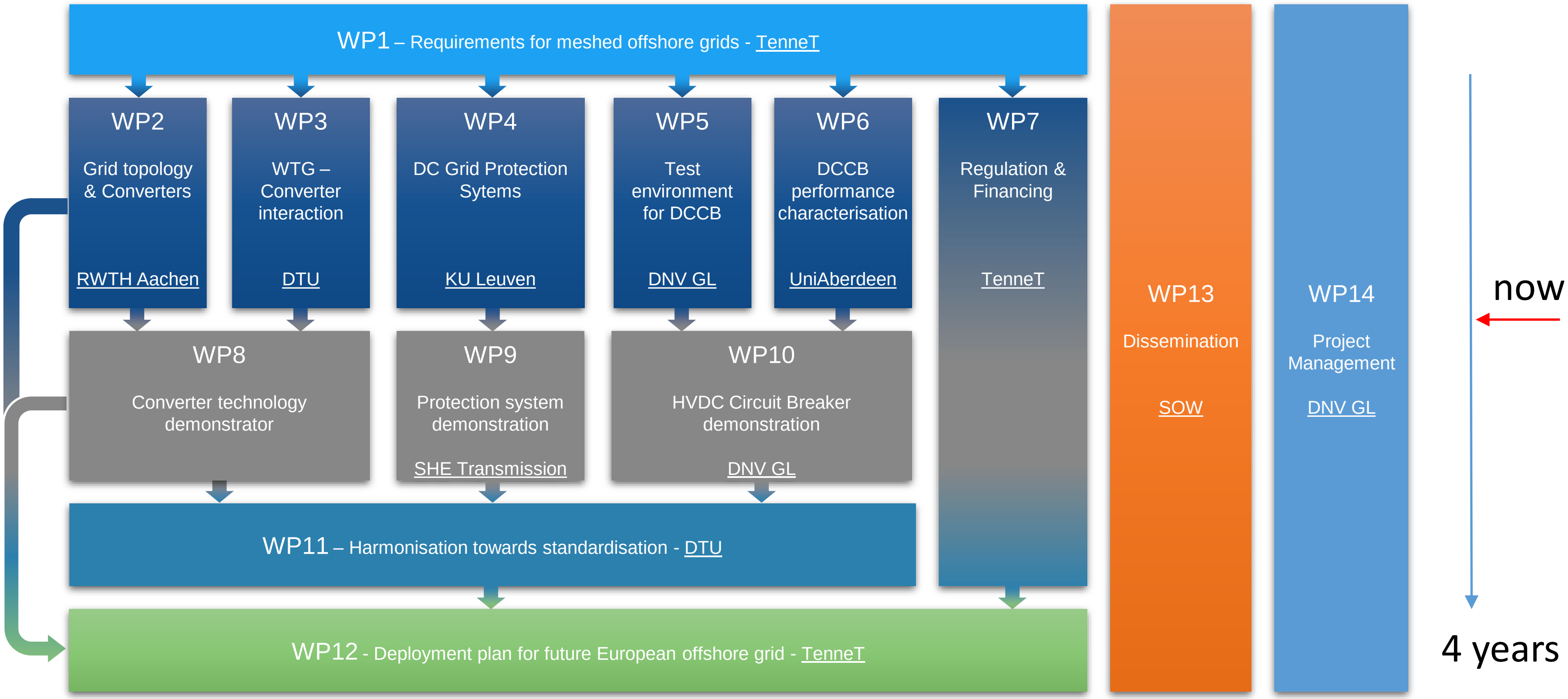
PROMOTioN

Objectives

1. Identify **technical requirements** and investigate possible **topologies** for **meshed HVDC offshore grids**
2. Develop **protection schemes** and **components** for HVDC grids
3. Establish components' **interoperability and initiate standardisation**
4. **Demonstrate cost-effective** offshore HVDC equipment
5. Develop recommendations for a coherent EU and national **regulatory framework** for HVDC offshore grids
6. Develop **recommendations for financing mechanisms** for offshore grid infrastructure deployment
7. Develop a **deployment plan** for HVDC grid implementation
8. **Disseminate** results

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

Project organisation

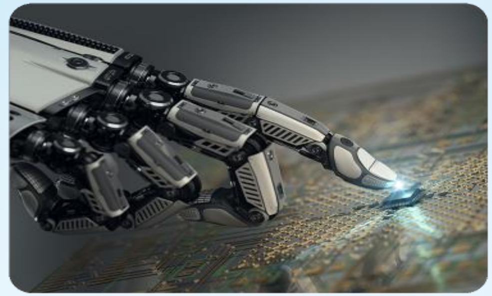


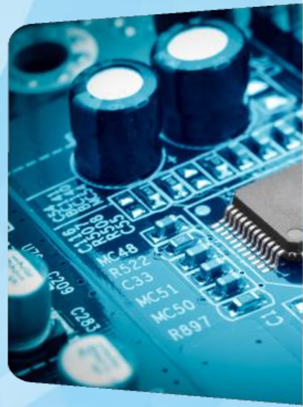
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691714.

Partners

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





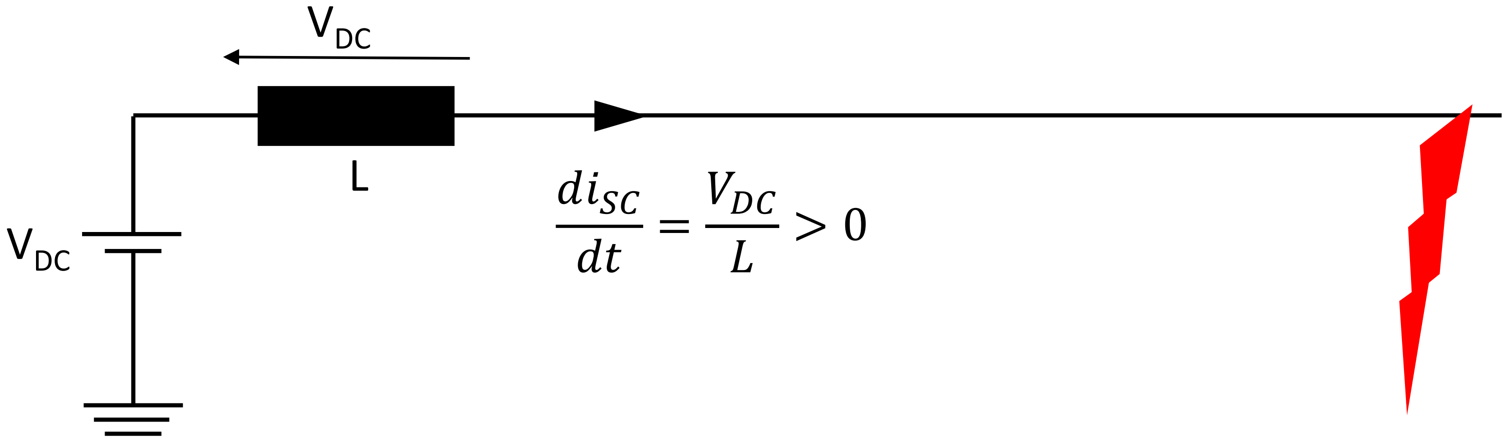


Test environment for HVDC circuit breakers

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

Test environment for HVDC circuit breakers

HVDC circuit breaker principle

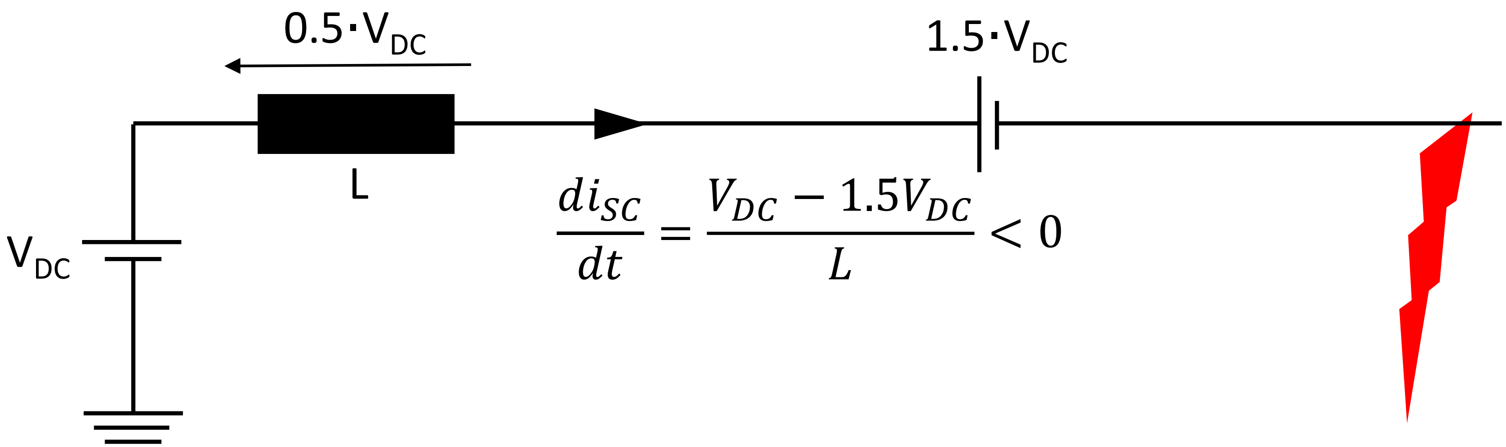


$$\frac{di_{SC}}{dt} = \frac{V_{DC}}{L} > 0$$

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

Test environment for HVDC circuit breakers

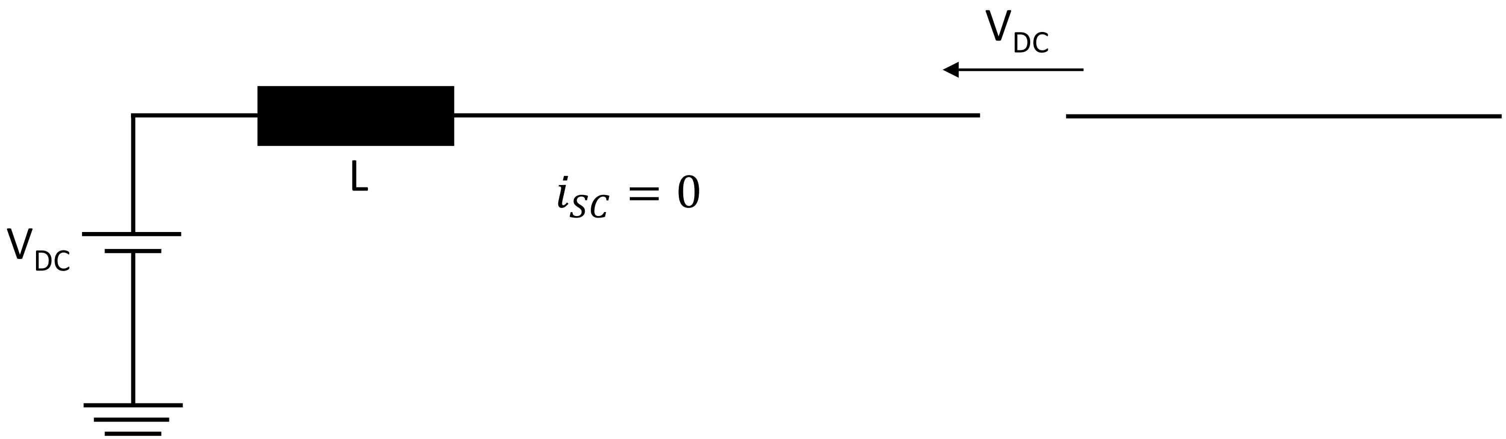
HVDC circuit breaker principle – current suppression by counter voltage



$$\frac{di_{SC}}{dt} = \frac{V_{DC} - 1.5V_{DC}}{L} < 0$$

Test environment for HVDC circuit breakers

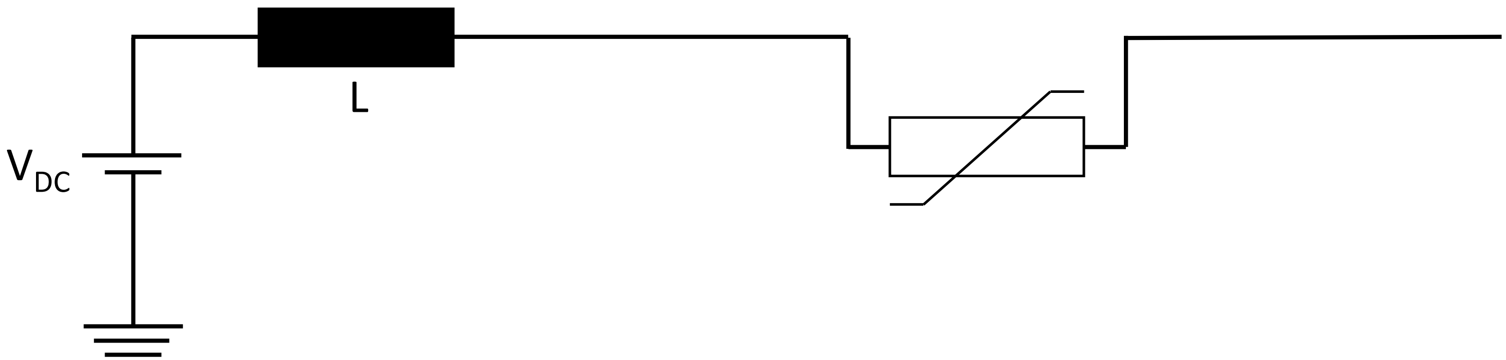
HVDC circuit breaker principle



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

Test environment for HVDC circuit breakers

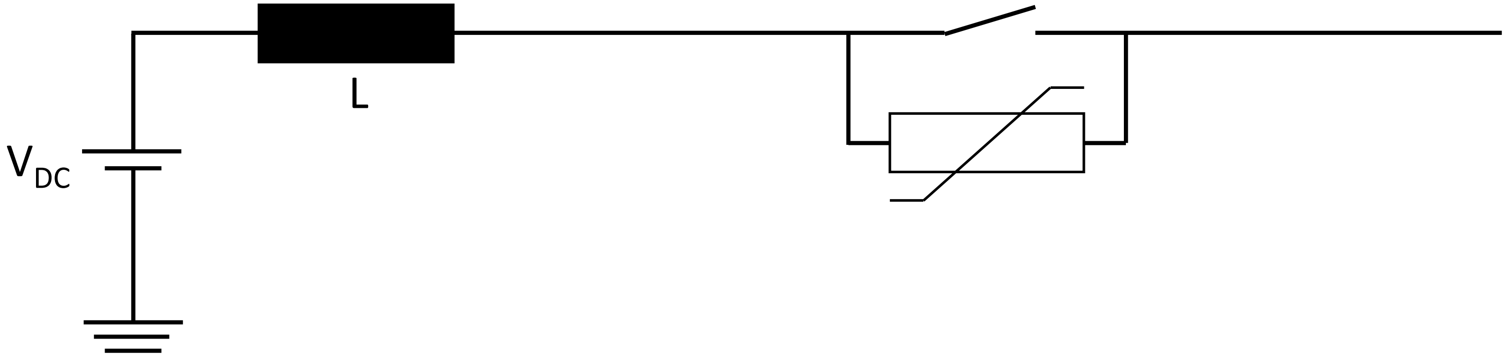
HVDC circuit breaker principle



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

Test environment for HVDC circuit breakers

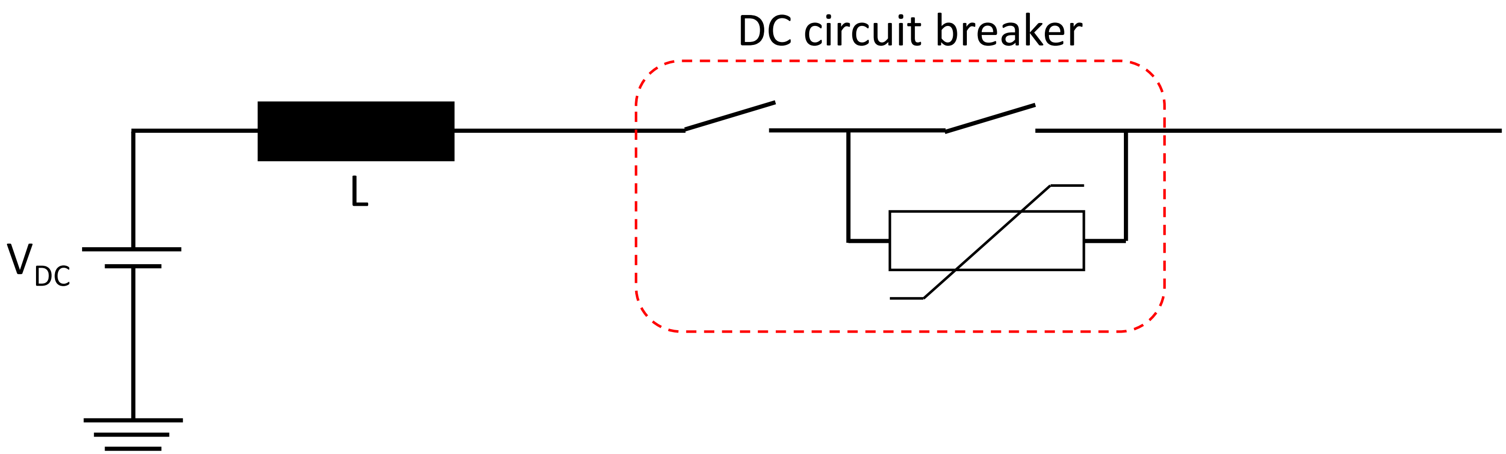
HVDC circuit breaker principle



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

Test environment for HVDC circuit breakers

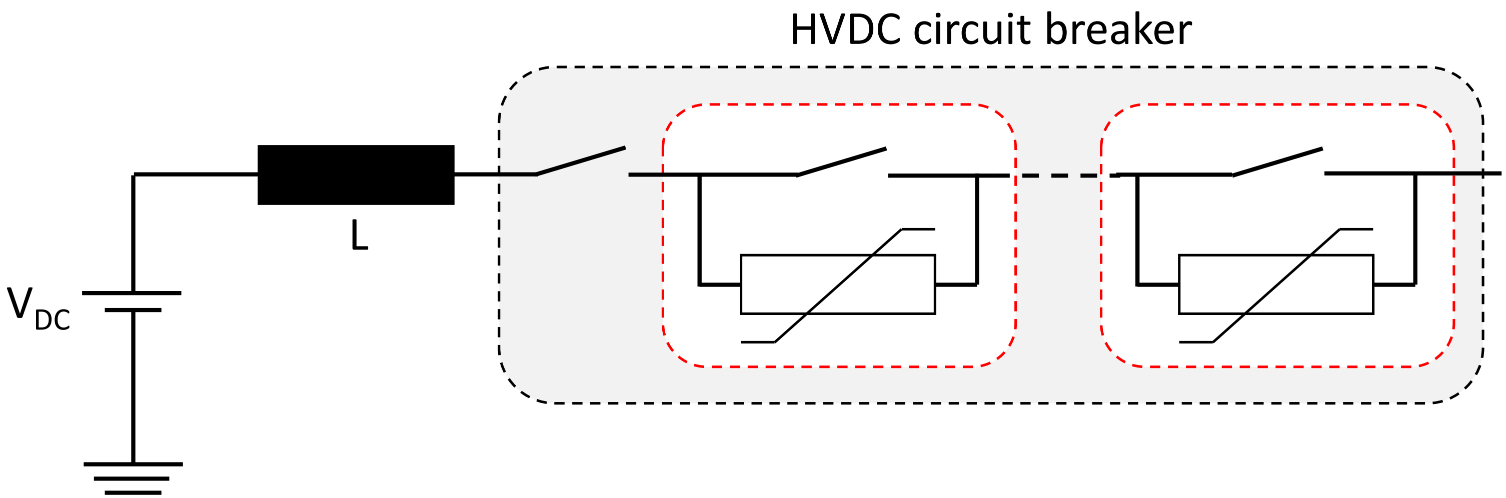
HVDC circuit breaker principle



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

Test environment for HVDC circuit breakers

HVDC circuit breaker principle - modularity

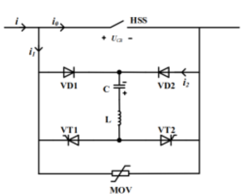


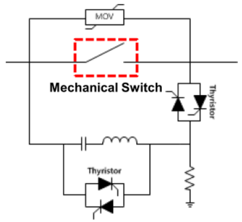
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691714.

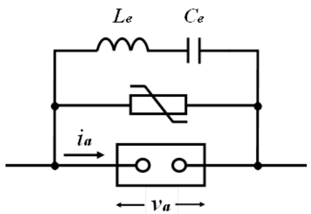
Test environment for HVDC circuit breakers

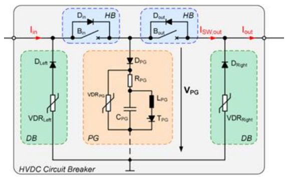
HVDC circuit breaker topologies

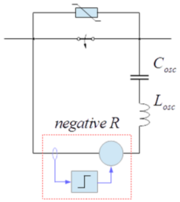
- Mechanical circuit breakers
  - Active current injection
  - Passive resonance
  - Active resonance

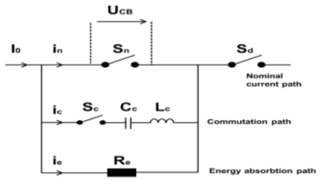




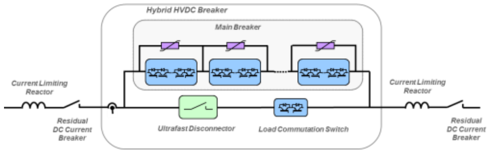


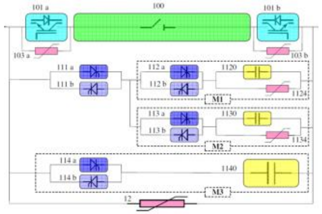


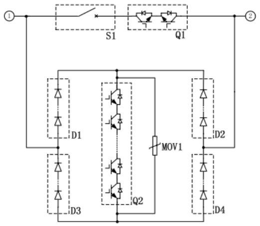


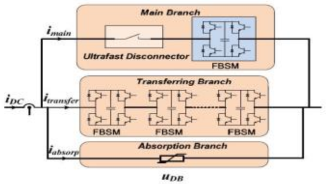


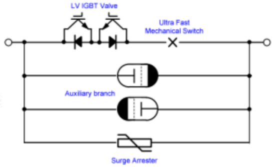
- Hybrid circuit breakers
  - Thyristor based
  - IGBT based









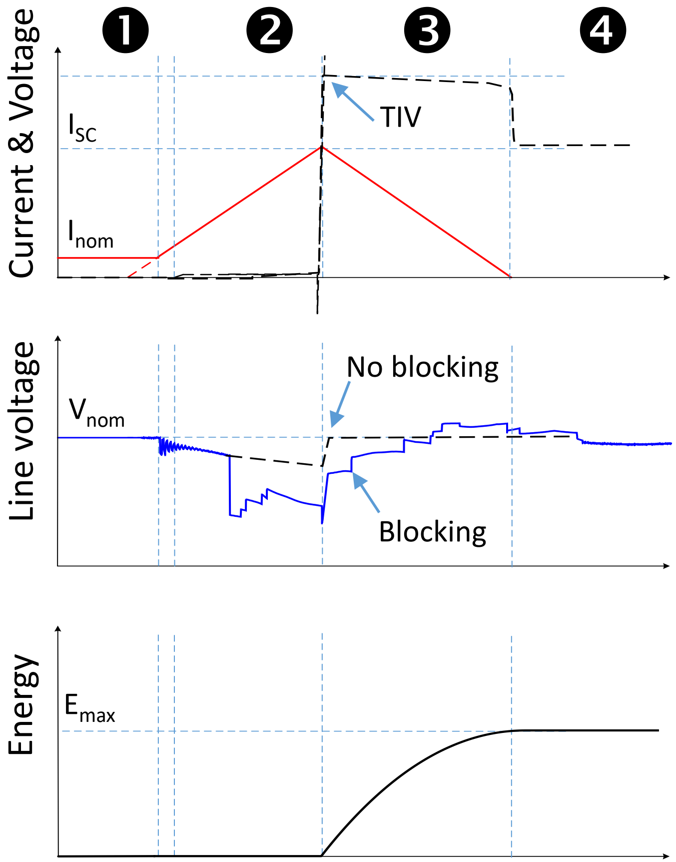


This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691714.

Test environment for HVDC circuit breakers

Current interruption test circuit requirements

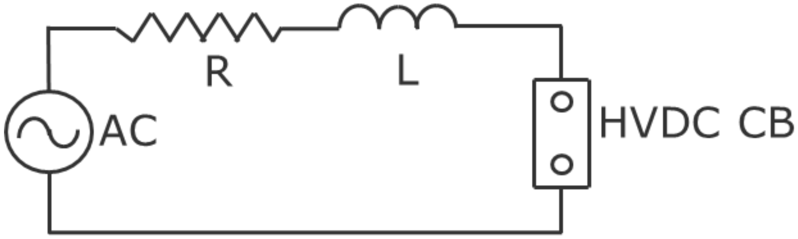
1. Normal operation
   - Apply heating – Pre-condition
   - Supply power to auxiliary systems
2. Current commutation time
   - Supply sufficient di/dt
   - Bidirectional
3. Fault suppression time
   - Supply sufficient energy
   - Withstand Transient Interruption Voltage
4. Post suppression
   - Apply DC voltage stress

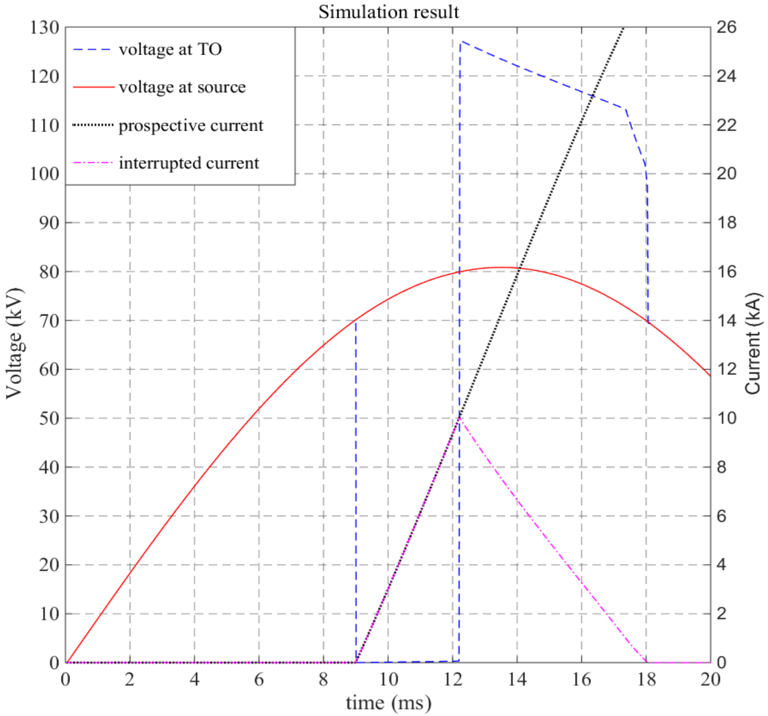


This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691714.

Test environment for HVDC circuit breakers

Reduced frequency AC short-circuit generator based test circuit



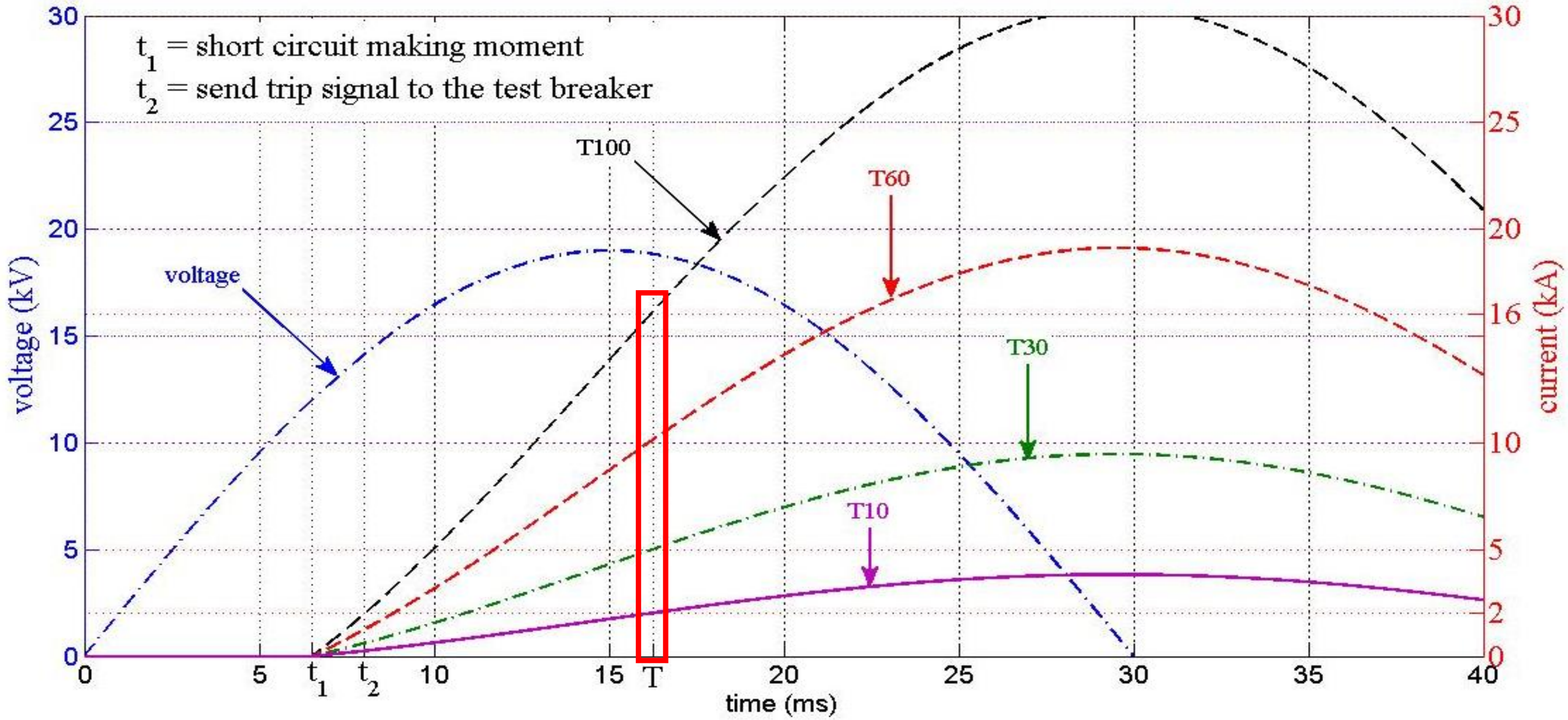


- Test circuit parameters
  - Generator frequency
  - Circuit inductance
  - Magnitude of source voltage
  - Making angle

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

Test environment for HVDC circuit breakers

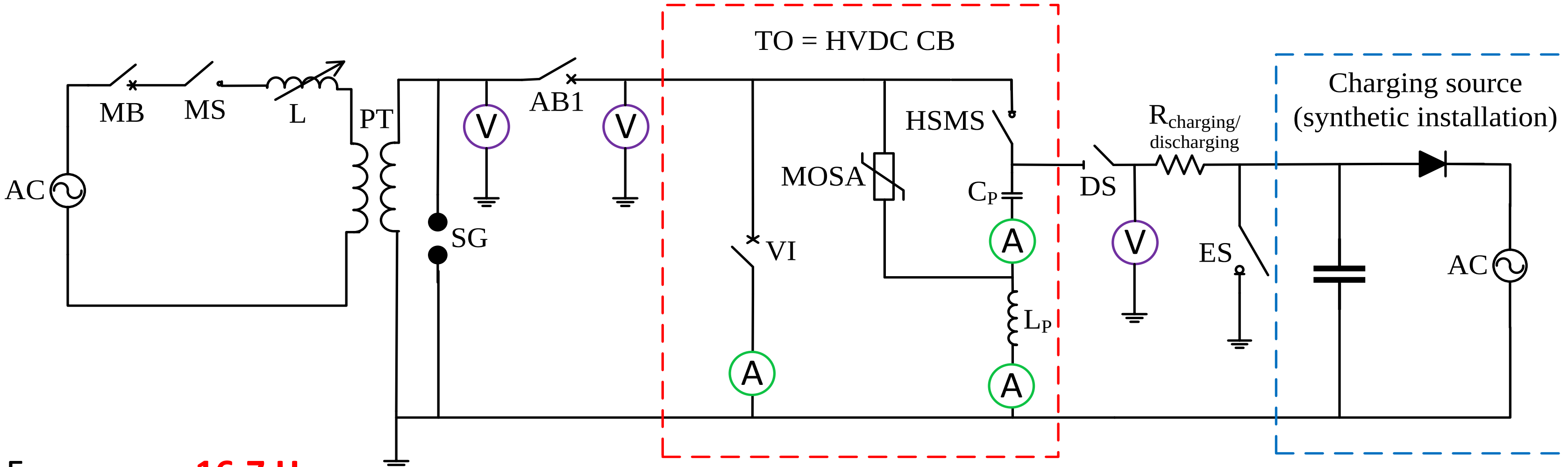
Realizing test duties



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

Test environment for HVDC circuit breakers

Implementation with mechanical circuit breaker with active current injection



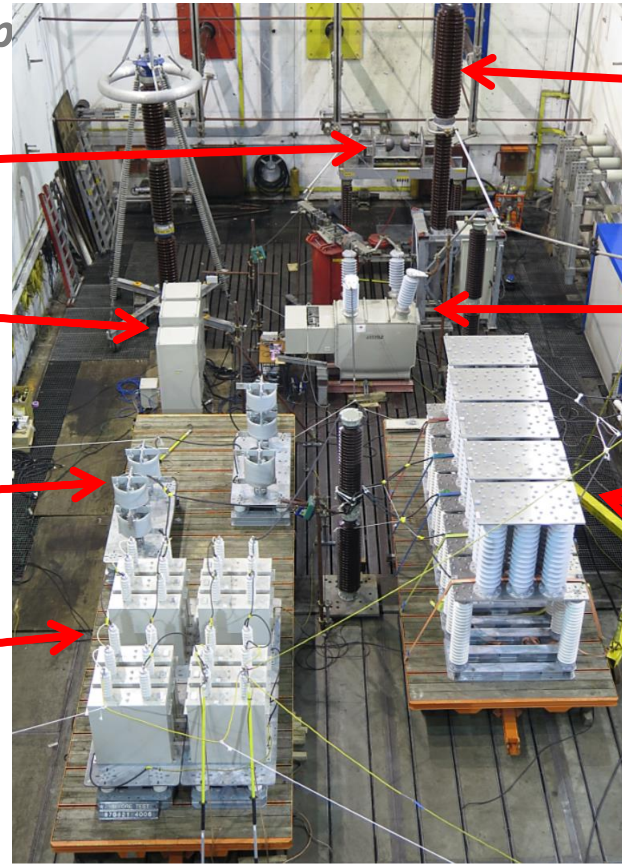
Frequency: **16.7 Hz**
Interrupting current: **±2 kA - ±16 kA**
Breaker operation time: **8 ms**
Voltage rating: **72.5 kV / 108 kV**
Energy dissipation: **1 - 4 MJ**

- VI: Vacuum Interrupter
- HSMS: High Speed Making Switch
- C_p: Capacitor
- L_p: Reactor

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

Test environment for HVDC circuit breakers

KEMA Laboratory set-up



Auxiliary SF_6 AC CB

Triggered making gap

DCCB Control Panel

HV and making vacuum interrupter switch

Reactors

Energy absorbing MOSA

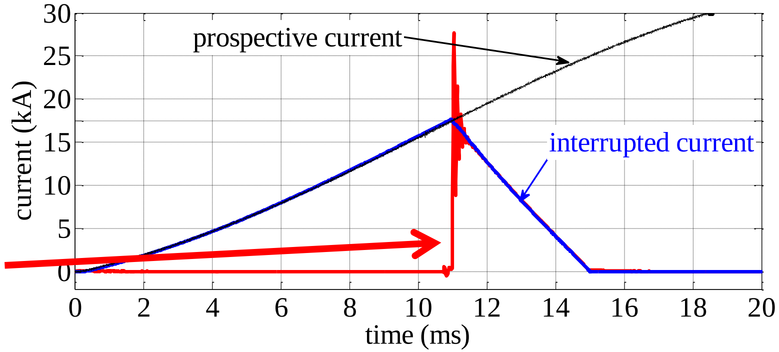
Counter current injection capacitors

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

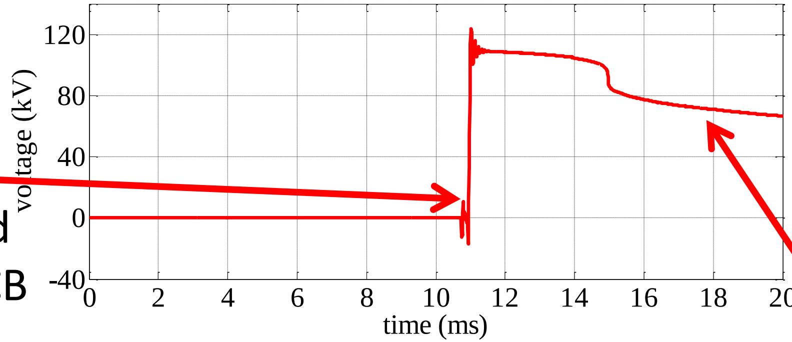
Test environment for HVDC circuit breakers

Test results – 16 kA positive & 3.6 MJ

current through MOSA

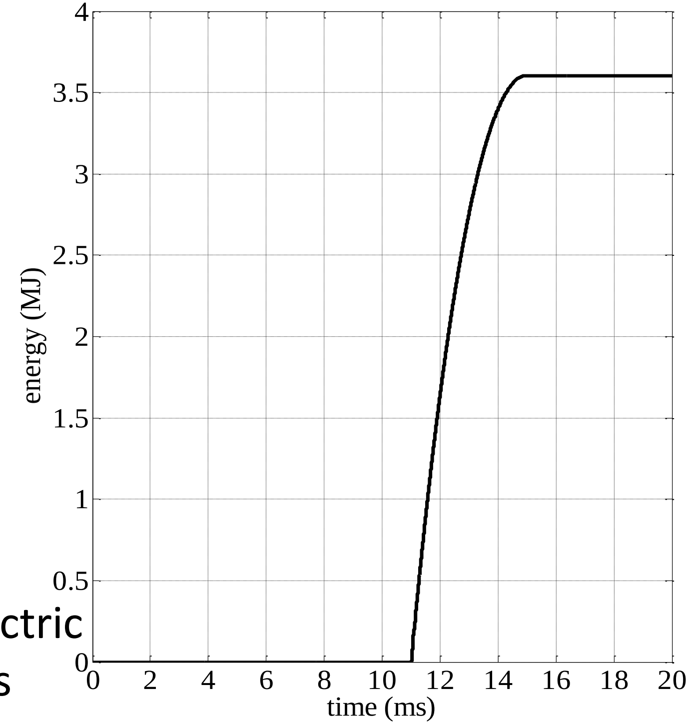


Counter voltage generated by HVDC CB



Dielectric stress

Energy absorbed by HVDC CB



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

Conclusions

- HVDC technology required to enable development of large scale offshore wind and interconnection capacity in Northern Seas
- Meshed grids potentially offer advantages over radial connections
- PROMOTioN addresses technical, regulatory, economical and legal challenges to the implementation of a meshed HVDC network
- HVDC circuit breaker technology still immature but developing quickly
- Reduced frequency AC short-circuit generators can be used to test DC circuit breakers' current interruption performance
- Current interruption of Mitsubishi Electric mechanical circuit breaker with active current injection successfully demonstrated in KEMA Laboratories

IEEE

Advancing Technology
for Humanity

IEEE