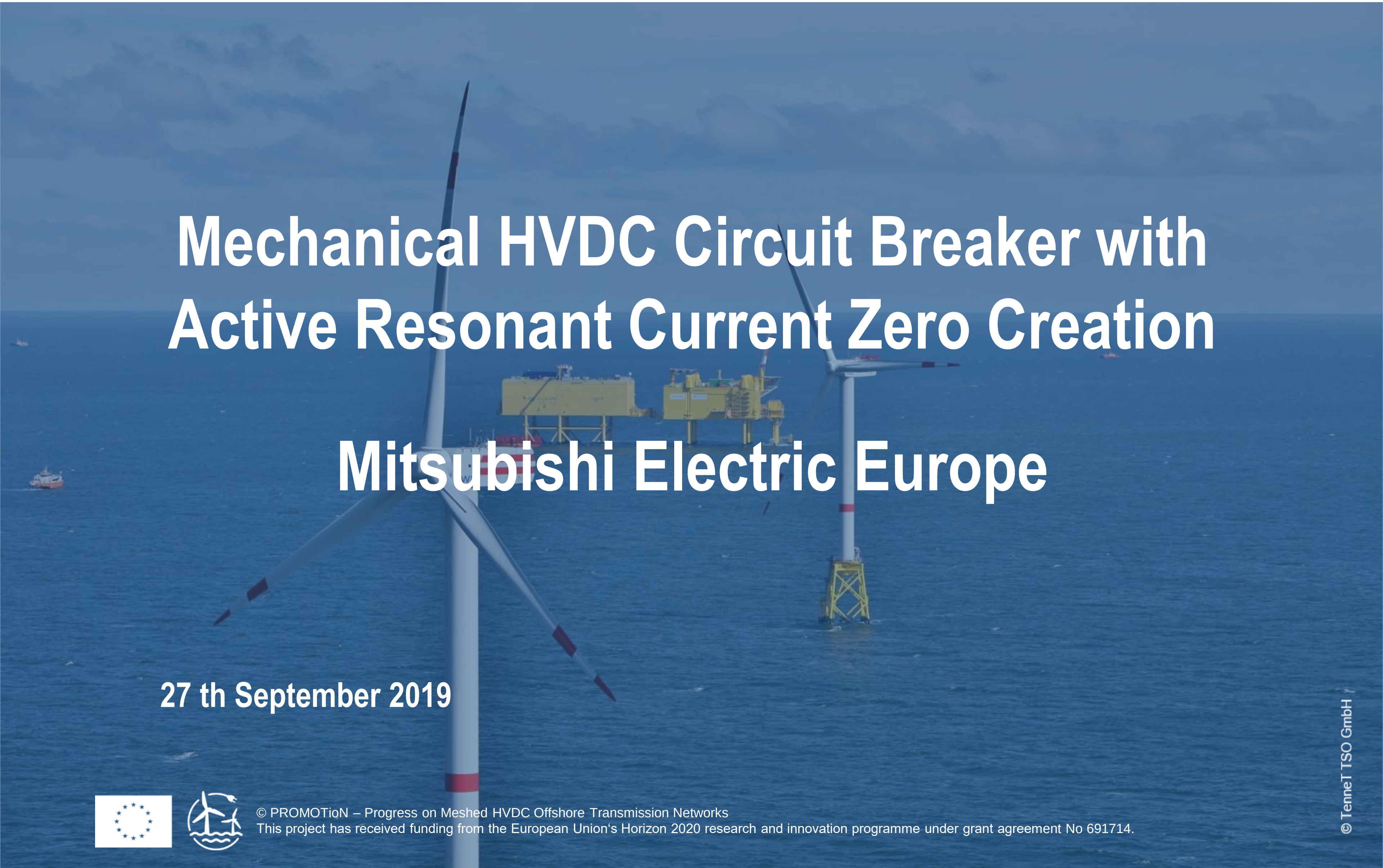
Mechanical HVDC Circuit Breaker with Active Resonant Current Zero Creation

Mitsubishi Electric Europe

27 th September 2019



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

Mitsubishi - Corporate Data

Mitsubishi Companies

- Over 40 Mitsubishi Group companies which share a common heritage
- Each Mitsubishi company now operates independently

Mitsubishi Electric Corporation: Electric & Electronics	**Mitsubishi Heavy Industries, Ltd:** Ship, Aircraft, Steel structures, Power Generation	**Mitsubishi Motors Corporation:** Automobiles	**Mitsubishi Corporation:** Trading
The Bank of Tokyo-Mitsubishi UFJ, Ltd.: Banking	**Nikon Corporation:** Cameras, Optical Equipment	**Tokio Marine & Nichido Fire Insurance Co., Ltd.:** Insurance	

Mitsubishi Electric's Origin

Tsukumo Shokai (1870) → **Mitsukawa Shokai (1872)** → **Mitsubishi Shokai (1873)** → **Mitsubishi Goshi Kaisha (1894)**

(Spin-off)

Mitsubishi Shipbuilding Company

(Spin-off)

Mitsubishi Electric Corporation (1921)

Yataro Iwasaki, Mitsubishi Founder (1835-1885)

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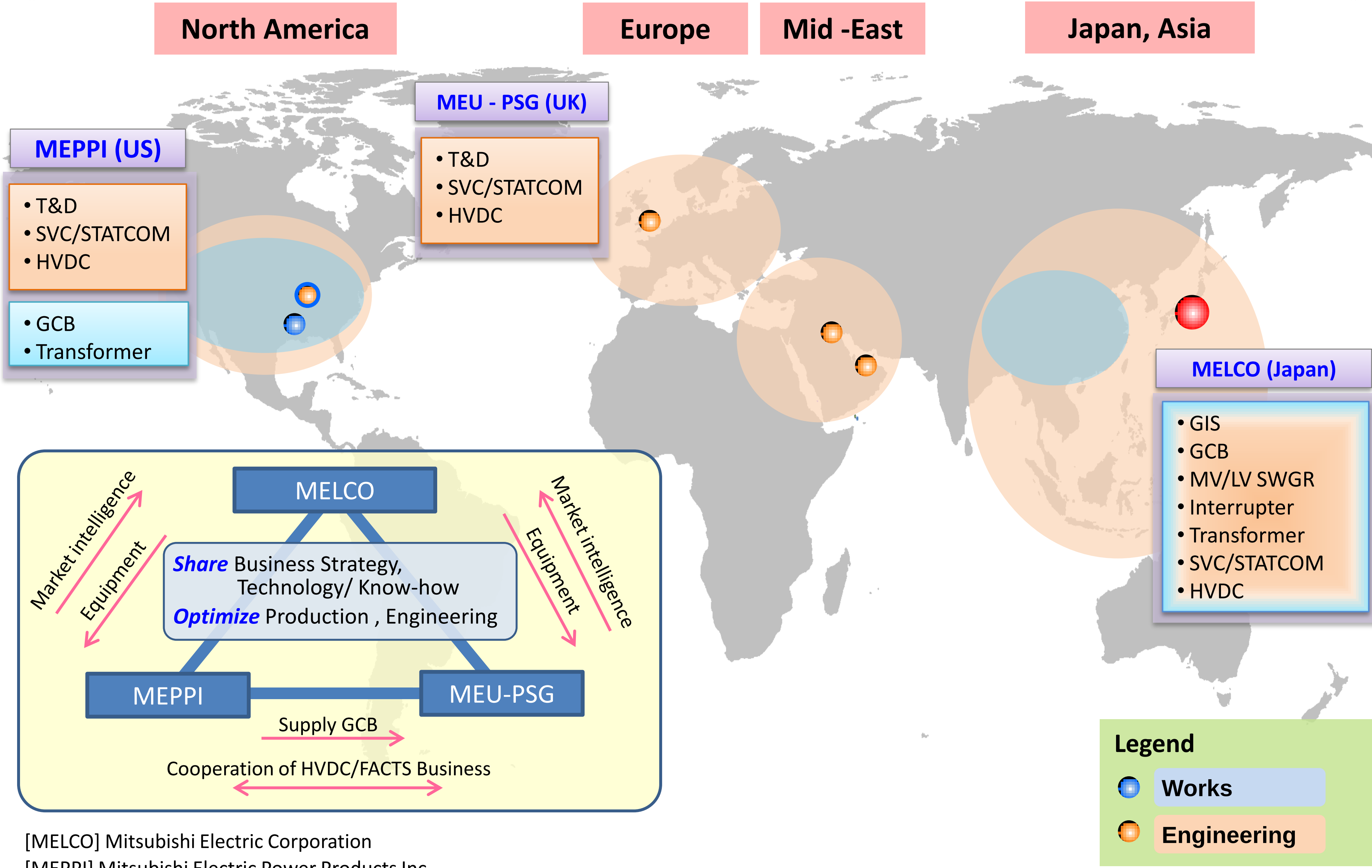
T&D Business Organization

for a greener tomorrow



[MELCO] Mitsubishi Electric Corporation
[MEPPI] Mitsubishi Electric Power Products Inc.
[MEU-PSG] Mitsubishi Electric Europe, Power Systems Group

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MITSUBISHI ELECTRIC
Changes for the Better

MEU - PSG Experience

for a greener tomorrow eco Changes

Isllington 145kV GIS Substation

UK Power Networks

Swansea North 420kV GIS Substation

nationalgrid

Blyth 400kV Substation - FTK

nationalgrid

Chilling 400kV Substation - FTK

nationalgrid

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MEU-PSG Focus

HVDC-DIAMOND™

- 50MW Back-Back VSC HVDC Verification Facility – Commissioned in Nov. 2018

SVC-DIAMOND™

- MMC-STATCOM and SVC
- More than 12000Mvar installed so far

Synchronous Condenser

- First Synchronous Condenser – 1929
- Mitsubishi has supplied > 2,137 large generators

GIS/ AIS Substation

- 35 Years of experience in Europe

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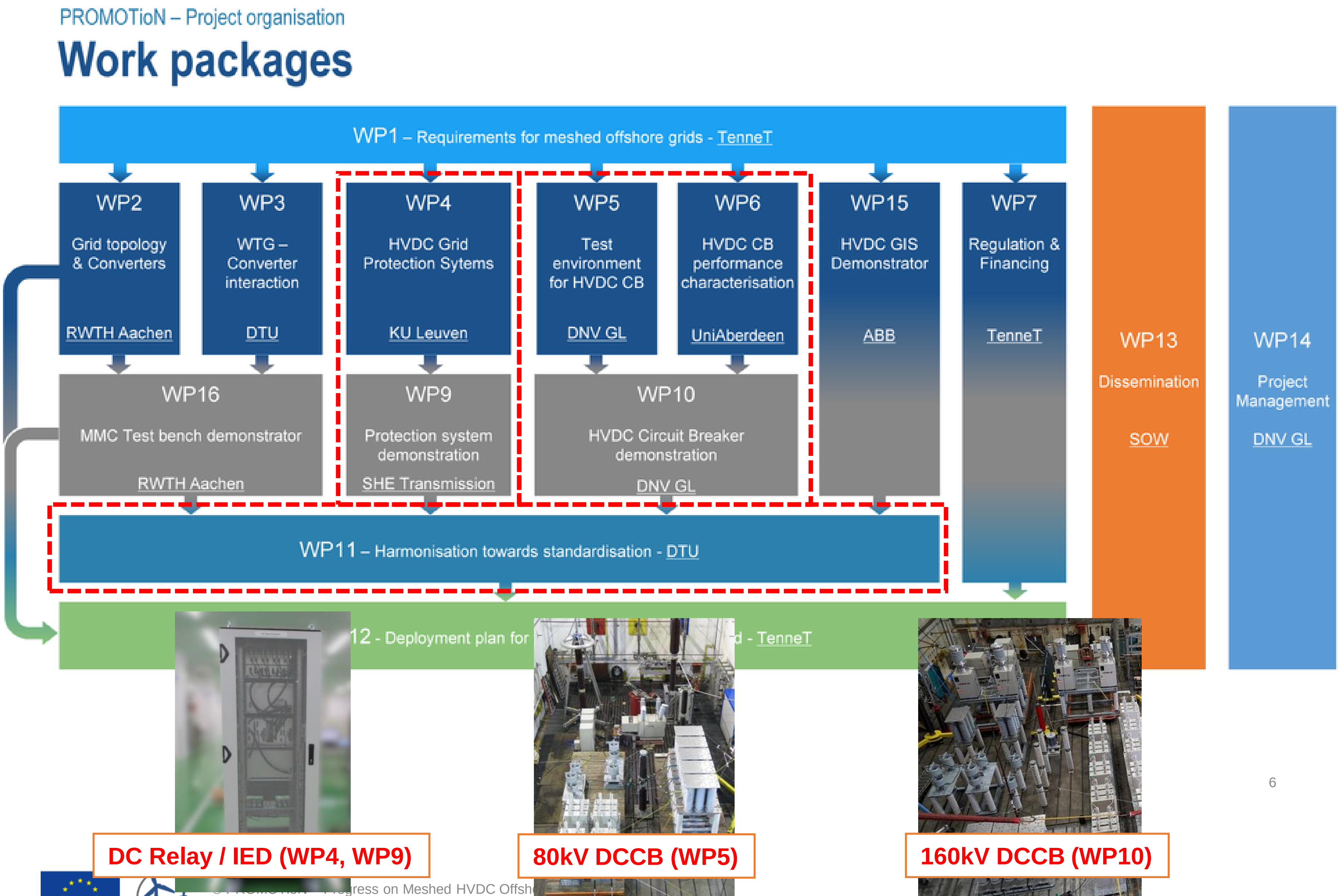
PROMOTioN and MEU



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HVDC circuit breaker requirements

- The requirements for HVDC circuit breakers (no international standards)

HVDC transmission system voltages: 525 kV/ 320 kV

Short-circuit currents: up to 16-20 kA depending on fault current clearing time

Fault current clearing (neutralization) time: 3-8 ms depending on system inductance

MOSA energy dissipation: 20-40 MJ depending on system inductance

Technology: Mechanical DCCB with current injection, Hybrid DCCB

- Rapid fault current clearing after the detection
- Rapid making switch operation for current commutation or current injection
- Long term reliability, Less maintenance works, Economic cost
- Large energy dissipation with multi-columns MOSA units
- Disconnection of residual current though MOSA units
- Rapid auto reclosing for HVDC OHL
- Negligible conduction losses

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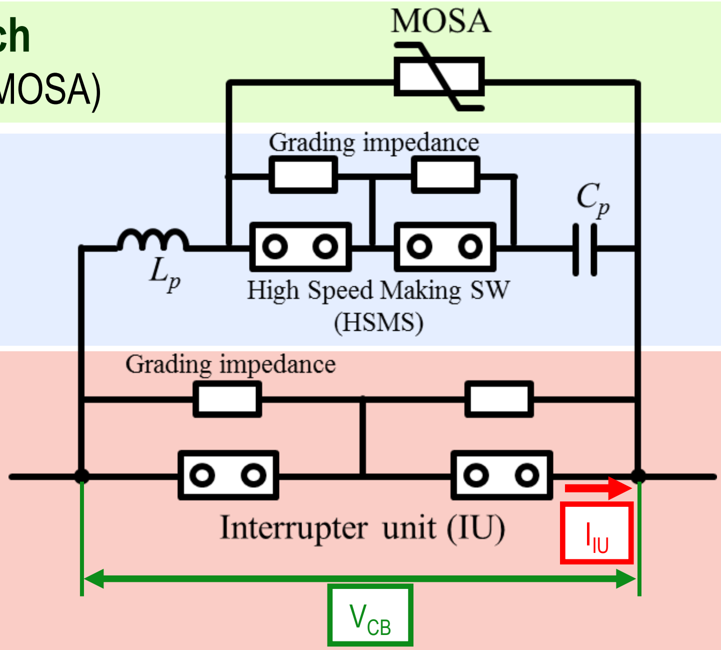
DCCB Topology
-Mechanical HVDC Circuit Breaker with Active Resonant Current Zero Creation-

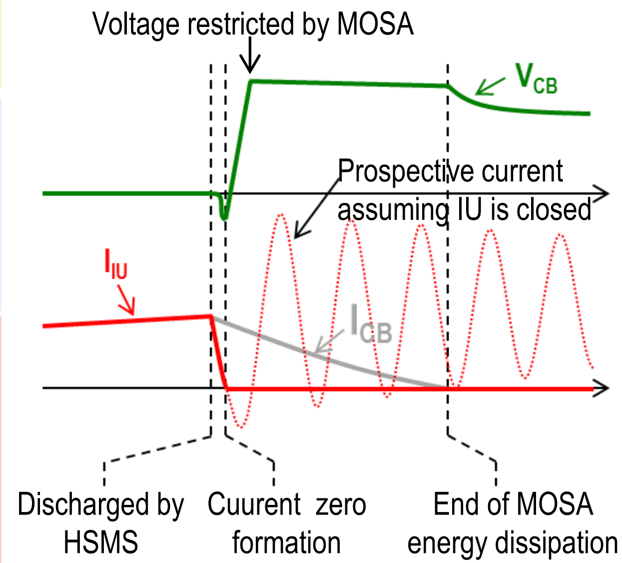
Energy Dissipation Branch
Metal Oxide Surge Arresters (MOSA)

Current Injection Branch
Making switch, Pre-charged capacitor and inductance

Circuit Breaker Branch
Vacuum Interrupter,
Main current carrying circuit



Configuration of double break mechanical HVDC circuit breaker



Voltage and current waveforms during current interruption process

- Current interruption process
  - Vacuum interrupter (VI) is used for the interrupter unit.
  - A current zero is created by superimposing high frequency current on DC current (I_{IU}) by discharging the charged capacitor (C_p).
  - Current is interrupted at first current zero.

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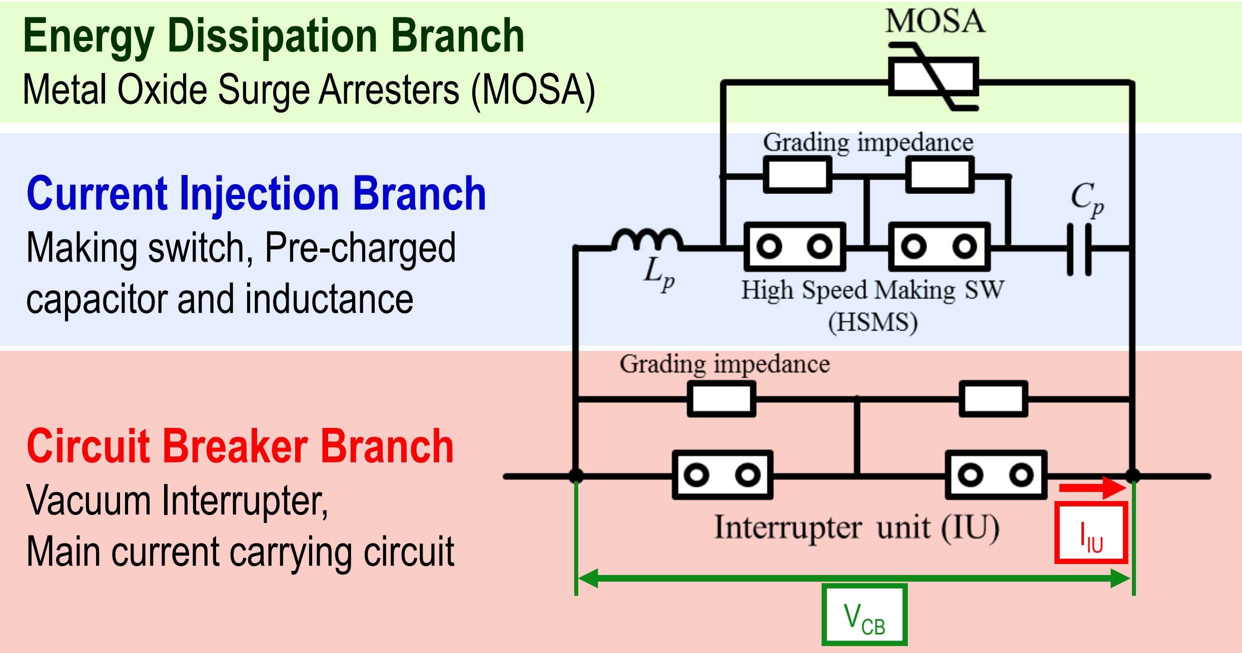

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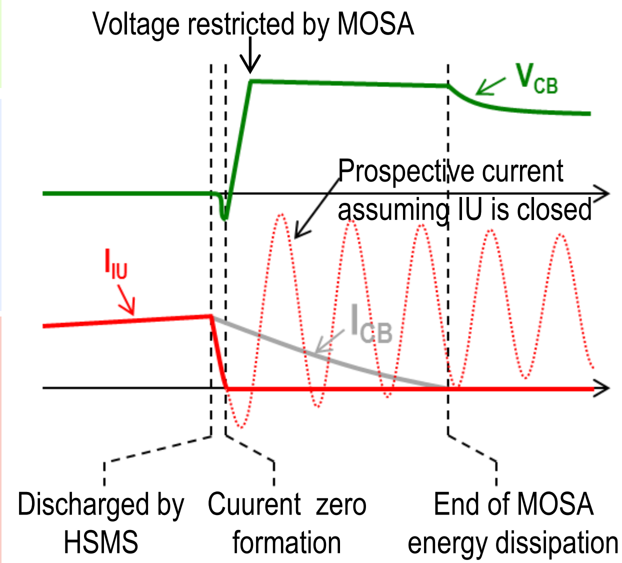

Voltage and current waveforms during current interruption process

- MOSA energy dissipation process
  - After current interruption, transient interruption voltage (TIV) is imposed on the interrupter.
  - TIV is clipped by the MOSA restriction voltage (typically about 1.5 p.u. of the rated voltage in accordance with V-I characteristic) and energy stored in inductive circuit is dissipated by the MOSA.

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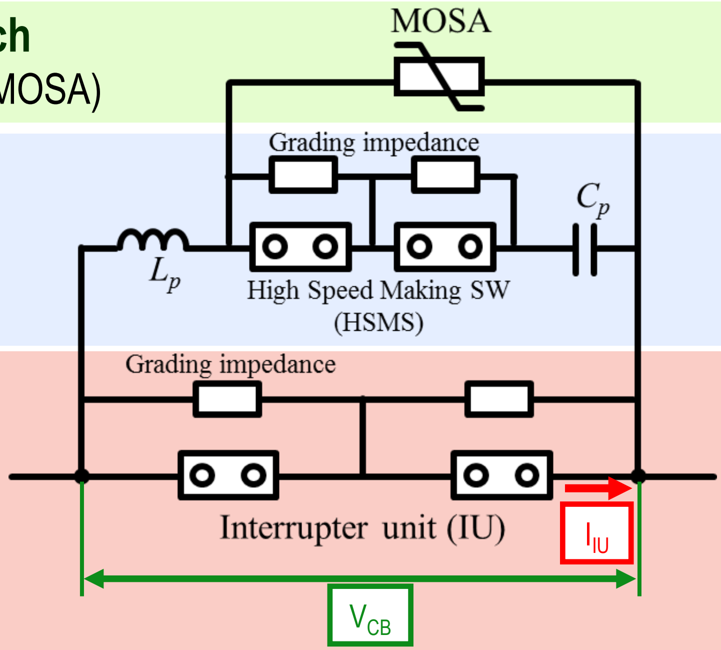

Configuration of double break mechanical HVDC circuit breaker

Double break 160 kV mechanical DCCB proto-type setup

- **MOSA energy dissipation process**
  - After current interruption, residual current through vacuum interrupter is commutated to the current injection branch, which charges the capacitor.
  - The transienet interruption voltage (TIV) is clipped by the MOSA restriction voltage (typically about 1.5 p.u. of the rated voltage in accordance with V-I characteristic) and energy stored in inductive circuit is dissipated by the MOSA.

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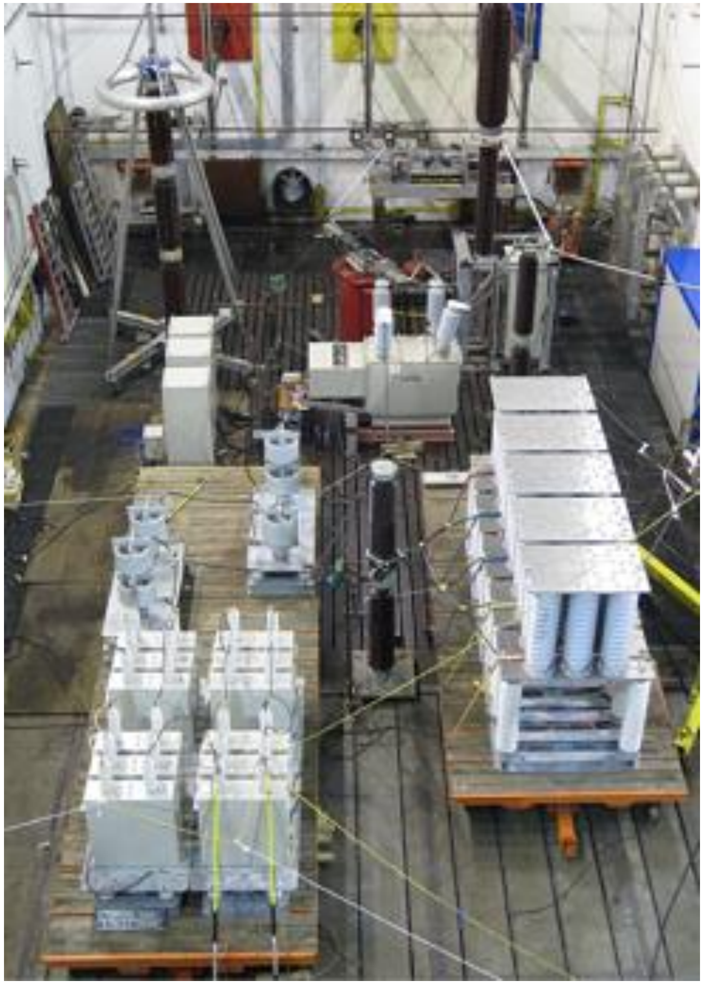
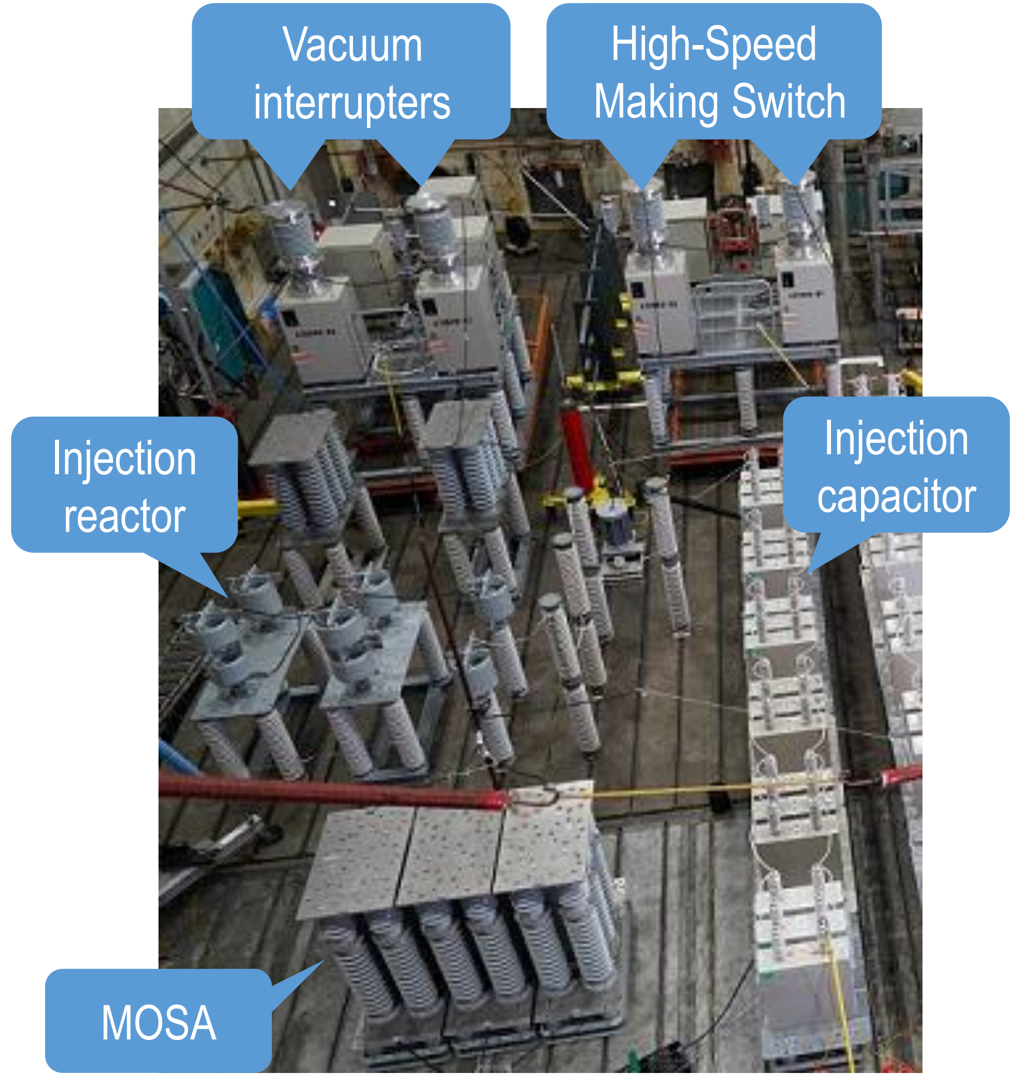
DNV-GL's KEMA High Power Laboratory



80 kV Unit DCCB testing
August and September, 2017



160/200 kV Double break DCCB testing
June, 2019

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Testing conditions of 160/200 kV DCCB demonstration

Test conditions

Items	Conditions
Test method	Reduced power frequency short-circuit generator method
Breaking current	0.2 kA, 2 kA, 16 kA
TIV peak	250 kV
MOSA dissipation energy	4 MJ maximum

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Energy Dissipating Requirements

- The energy capacity of MOSA applied to DC circuit breaker is required to cope with two interruptions with rated short circuit current (e.g. DC 16 kA).

- Typical MOSA unit is designed with high homogeneity multi-columns connected in parallel.

Homogeneous MOSA elements are chosen by an element screening.

Homogeneous MOSA columns are chosen by a column screening

Variation of Residual Voltage: < 0.2%
V-I characteristic of a Multi-column MOSA are verified

Typical MOSA energy capacity required for 320 kV DC circuit breakers

$$\mathbf{E = \frac{1}{2}LI^2 = \frac{1}{2} \times 200\,mH \times (16\,kA)^2 \approx 24\,MJ}$$

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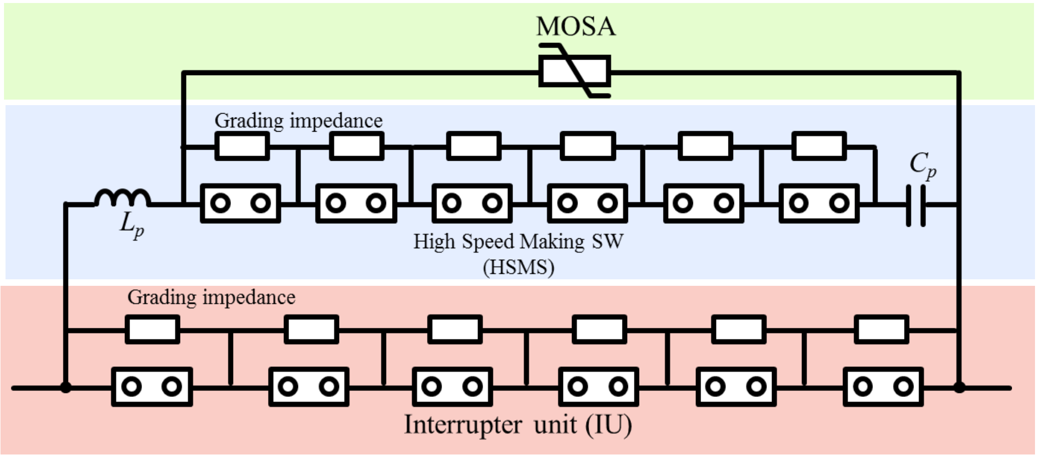
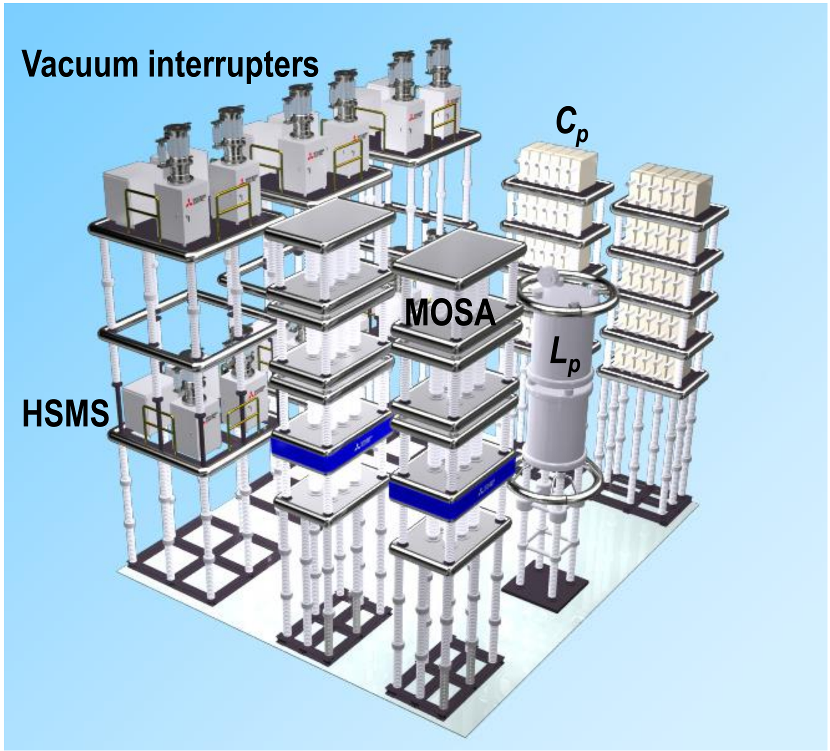
525/600 kV 16 kA DC circuit breaker

- Mechanical HVDC Circuit Breaker with Active Resonant Current Zero Creation -



Configuration of 6 break mechanical DCCB



Conceptual design of 525/600 kV DCCB with 6 VI

- High voltage DCCB can be realized by connecting VI in series.
- The conceptual design shows the 525/600 kV DCCB, connecting six VIs in series.

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Summary

- Double break 160/200 kV mechanical DCCB was demonstrated at DNV-GL KEMA HPL lab.
- Interruption test at DCCB voltage of 160 kV, 0.2 ~ 16 kA was interrupted successfully.
- Successfully interrupted bi-directional current of 16 kA at first current zero.
- Temperature rise of each MOSA column was uniform after the interruption test.
- It shows a good result that MOSA column of parallel connection is applicable for HVDC circuit breaker.

Multi-break HVDC circuit breaker with current injection applied with the multi-column well-screening MOSA units as well as the equal voltage division technique can be feasible for 525 /600 kV,16 kA ratings and above.

Mitsubishi Electric is ready for field installment of HVDC circuit breakers.

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