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Changes for the Better

for a greener tomorrow

Development of HVDC circuit breakers with current injection

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Mitsubishi Electric Power Business

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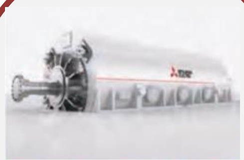

Turbine Generator

Turbine Generator Supply
OVER 2,000
Worldwide Since 1908

Generation
Efficiency 99%
Maximum Output 870MVA

Switchgear

Up To 1,100kV with High Reliability
OVER 1600 GIS/GCB
Supply Worldwide Since 1965
Low Failure Rate by Spring Mechs
Low Gas Leak Rate < o.1%/year

Vacuum switchgears
Leading Manufacturer in Japan
4,600,000 VI / 1,200,000 VCB
C-GIS with VCB up to 72kV

Power Electronics

FACTS / HVDC
World First STATCOM in 1991
450MVar STATCOM in 2012
LCC HVDC System in 2000
MMC with MELCO IGBT Device

Reliable System
HVDC Verification Facility in 2018

FTK solution
With Overseas Affiliates

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Mitsubishi Power Electronic Devices

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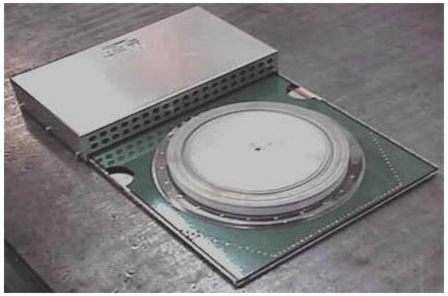
GTO: Gate Turn-off Thyristor (4.5kV,3kA) ～(6kV, 6kA)

- Large capacity → Less devices, Compact
- Very high reliability
- Low conduction loss
- Needs snubber circuit (losses increased)

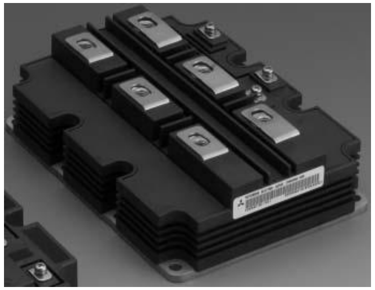
Kansai - Inuyama 80MVar (1991)
Shin-Shinano BTB 53MVA(1998)



GCT: Gate-Commutated Turn-off Thyristor (6kV,6kA)

- Same merits with GTO, plus
- Snubber-less → Total losses reduced by half
- Sufficient capacity and functions for current usage → no more development

Vermont - Essex 133MVar (2001)
SDGE – Talega 100MVar (2003)
Kansai – Kanzaki 80MVar (2004)
Chubu – Toshin 450MVar (2012)
Kansai – Inuyama 130MVar (2013)



IGBT: Insulated Gate Bipolar Transistor for MMC

- Reliable, reasonable cost
- Capacity, efficiency, and robustness improved rapidly
- MMC technology provides systematic reliability with generic devices

Seatle Iron & Metal 5MVar (2000)
Manitoba - Bloodvein 12MVar (2003)
Mitsubishi – Itami BTB 1MVA (2011)

1990 2000 2010

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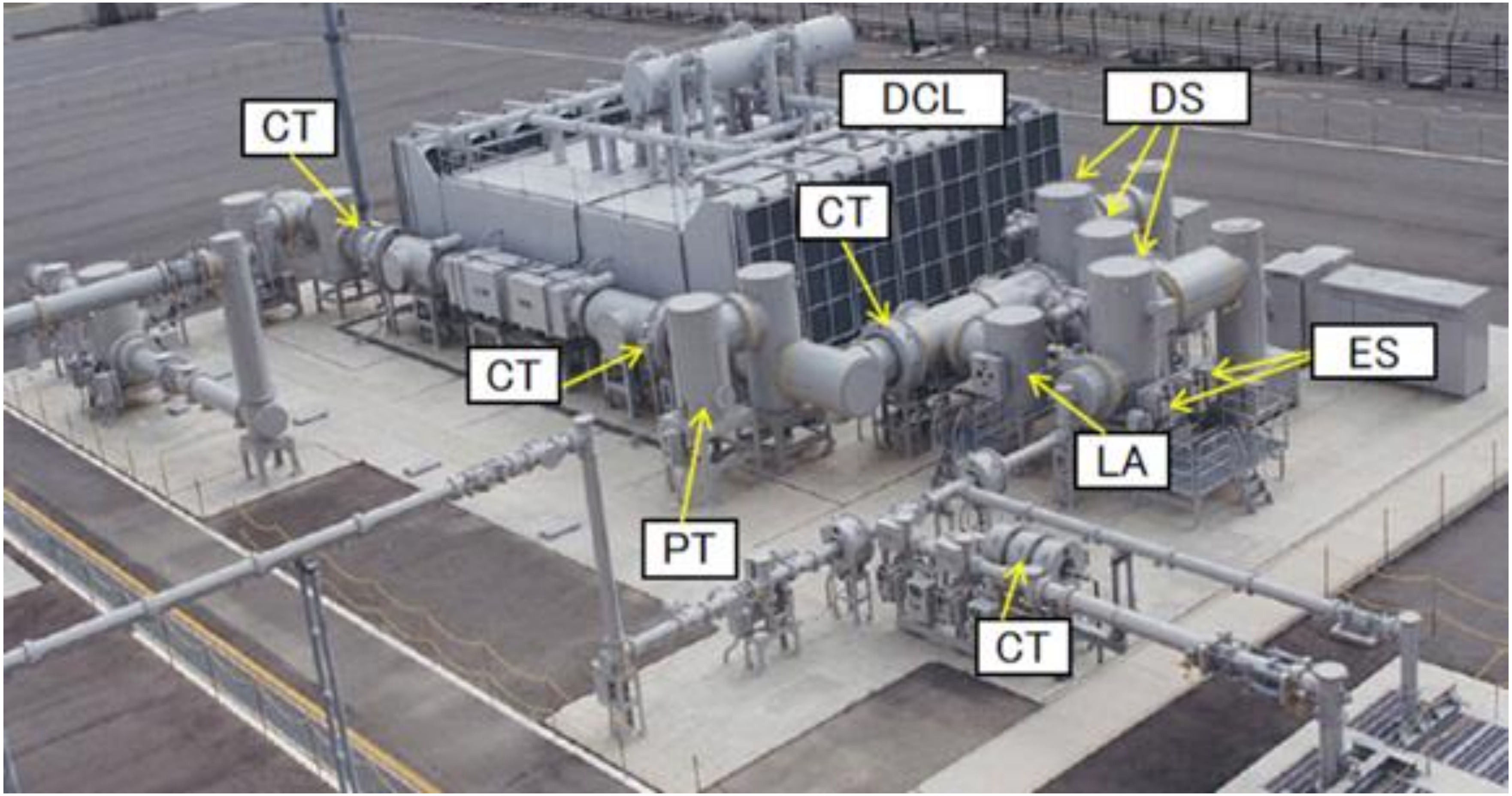
HVDC switchgears (GIS)



500 kV DC-Disconnecting switches & Earthing switches, DC-CT & VT, DC-MOSA (LA) used for 500 kV-DC gas insulated switchgear commissioned in 2000

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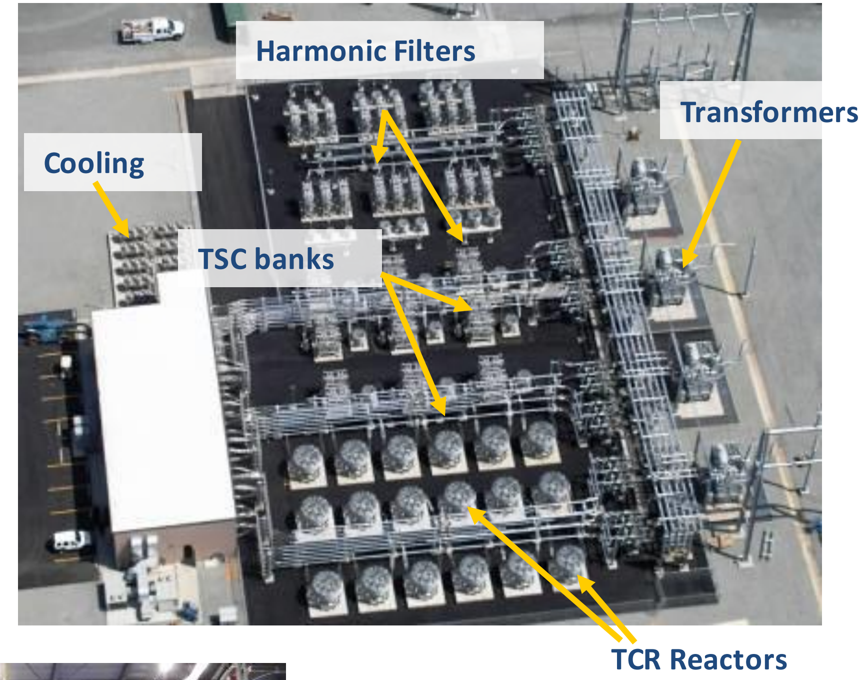
FACTs and HVDC Products

HVDC Transmission

SVC (Static Var Compensator)



VSC testing facility

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HVDC circuit breaker requirements

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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 vs 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
- Minimum current carrying loss

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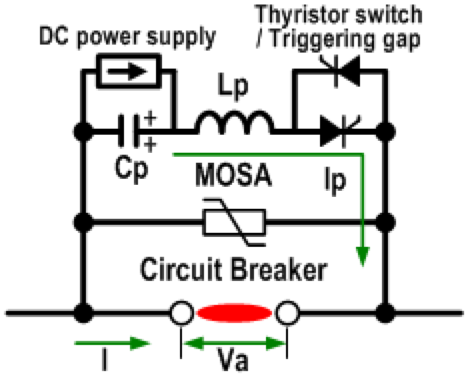
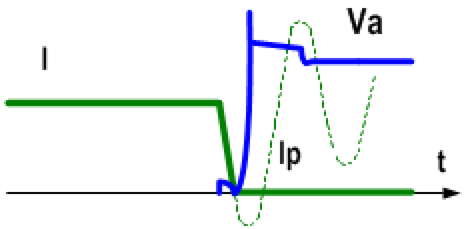
DCCB technologies for multi-terminal HVDC

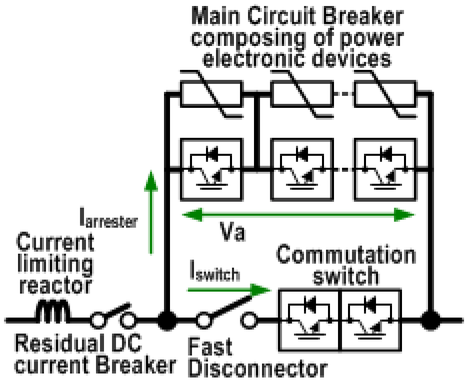
Mechanical DC CB with current injection

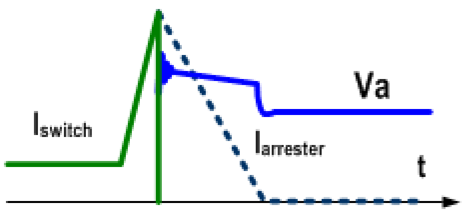




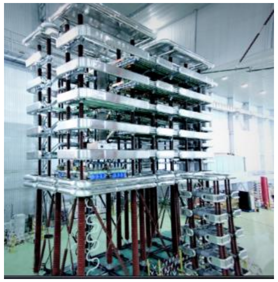
Pre-charged capacitor imposes an reverse current on DC current and instantly creates the current zero.

Hybrid mechanical-electronic DC CB





IGBT devices connected in parallel and series block DC fault current.



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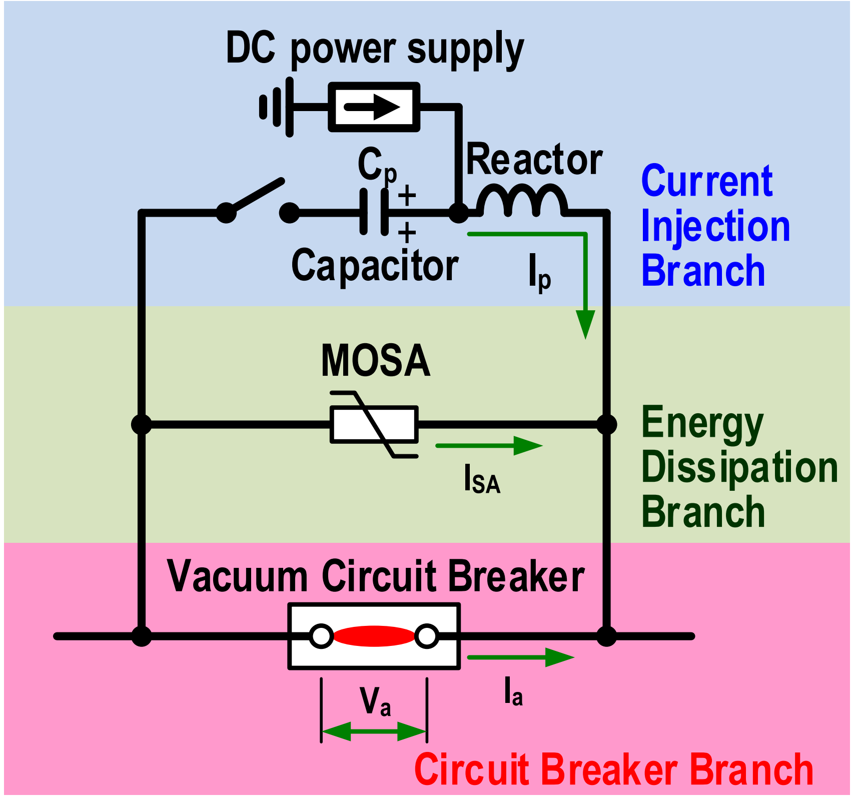
Topology of mechanical DC circuit breaker



Current Injection Branch
Making switch, Pre-charged capacitor, its DC power source and inductance

Energy Dissipation Branch
Large capacity Metal Oxide Surge Arresters (MOSA)

Circuit Breaker Branch
Vacuum Interrupter, Main current carrying circuit

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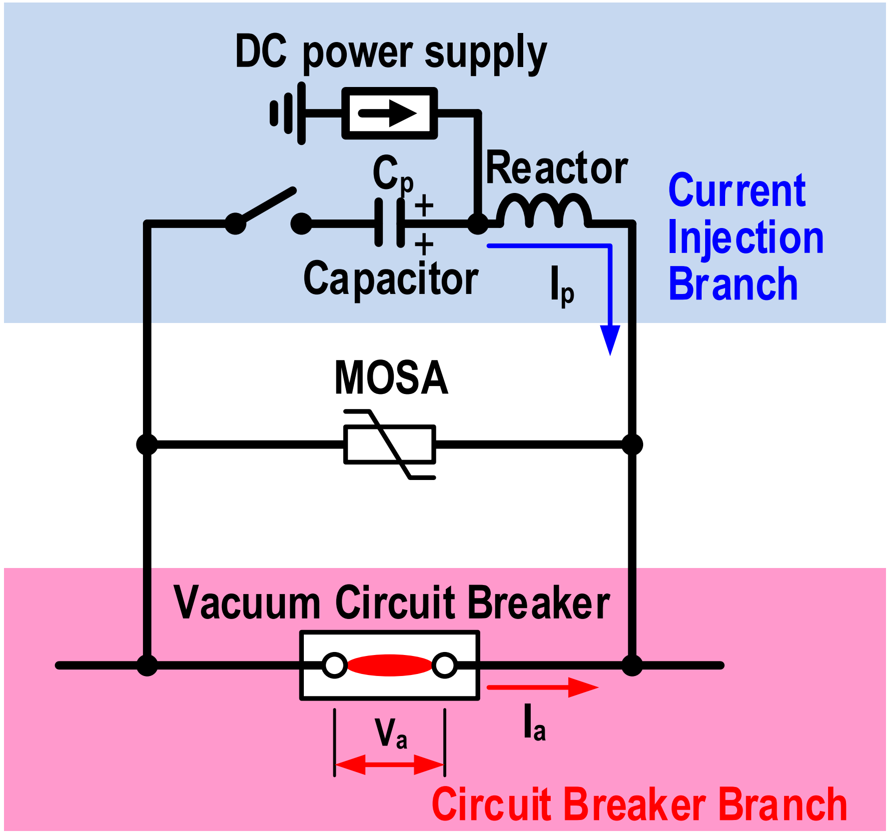
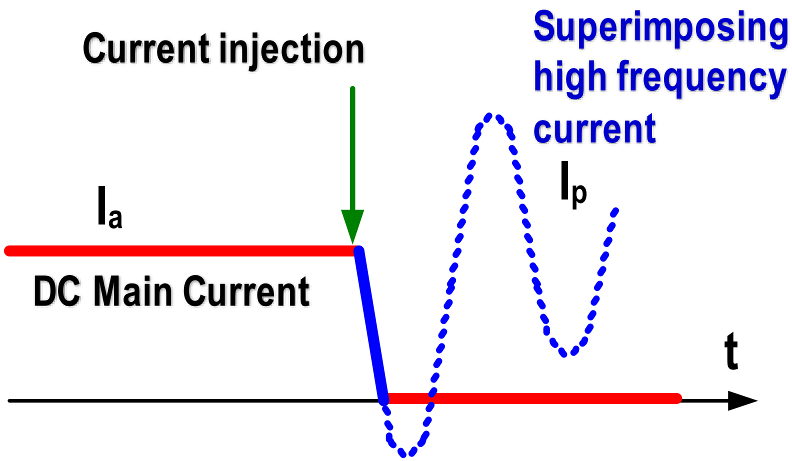
Current zero creation scheme

A current zero is created by superimposing high frequency current on DC current charged by the capacitor bank.





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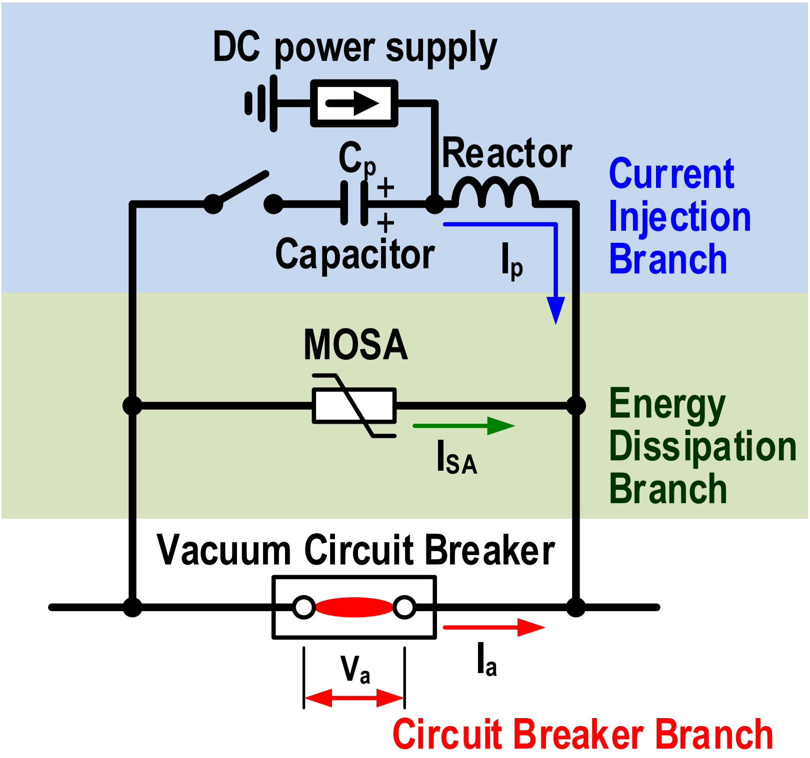
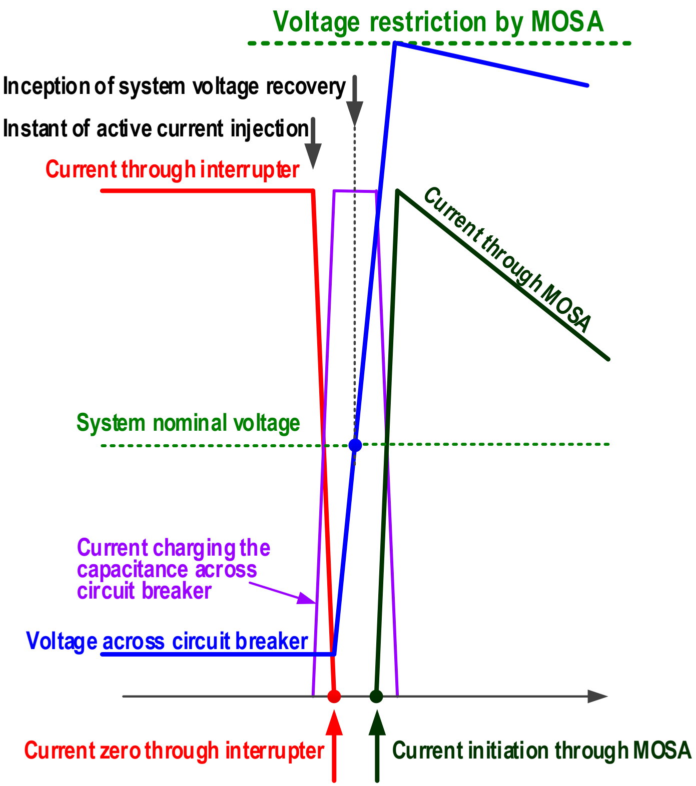
MOSA energy dissipation process

After current injection, residual current through vacuum circuit breaker is commutated to the current injection branch, which charges the capacitor.

The voltage across the vacuum interrupter is quickly recovered and surpassed beyond the nominal system voltage.

Then the transient recovery voltage is clipped by the MOSA restriction voltage (typically about 1.5 pu 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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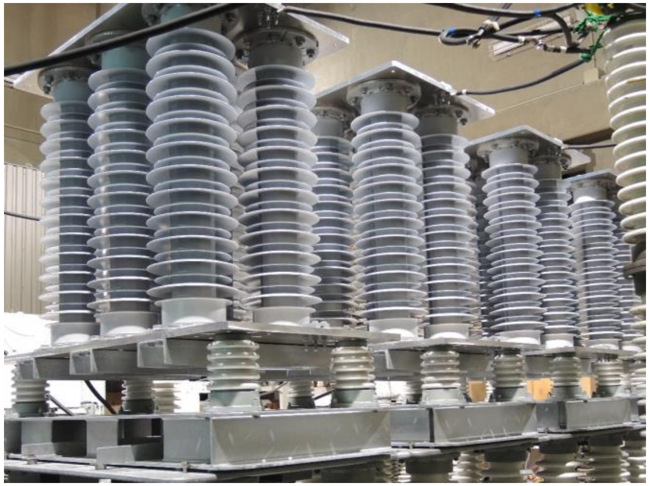
Energy Dissipating Requirements

The energy capacity of MOSA applied to DC circuit breaker is required to cope with **twice 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

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

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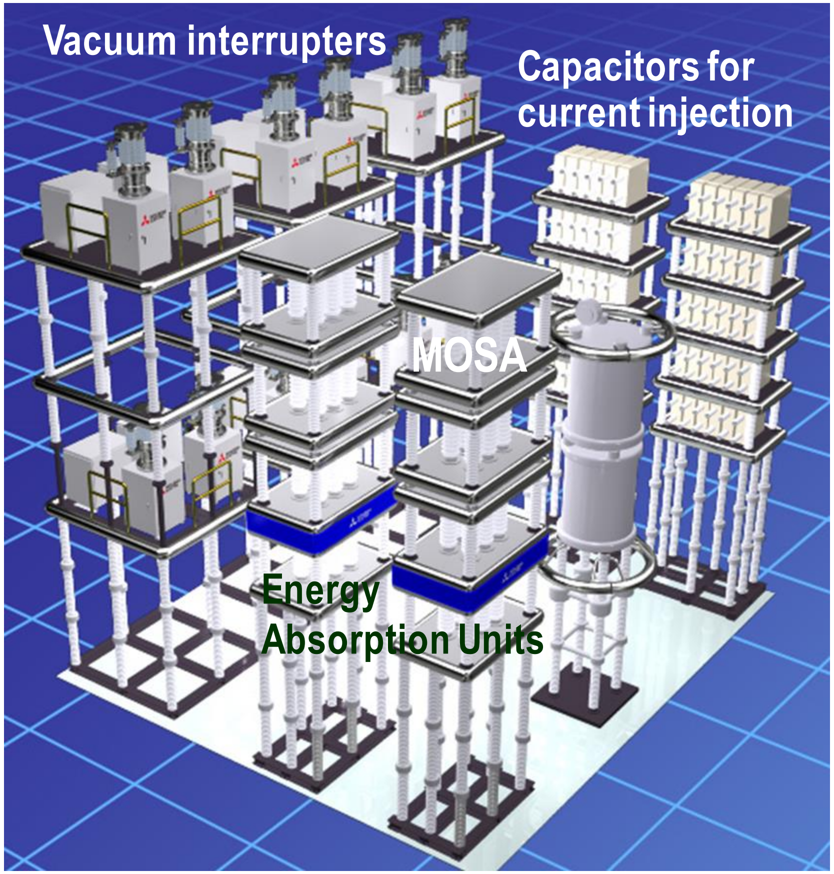
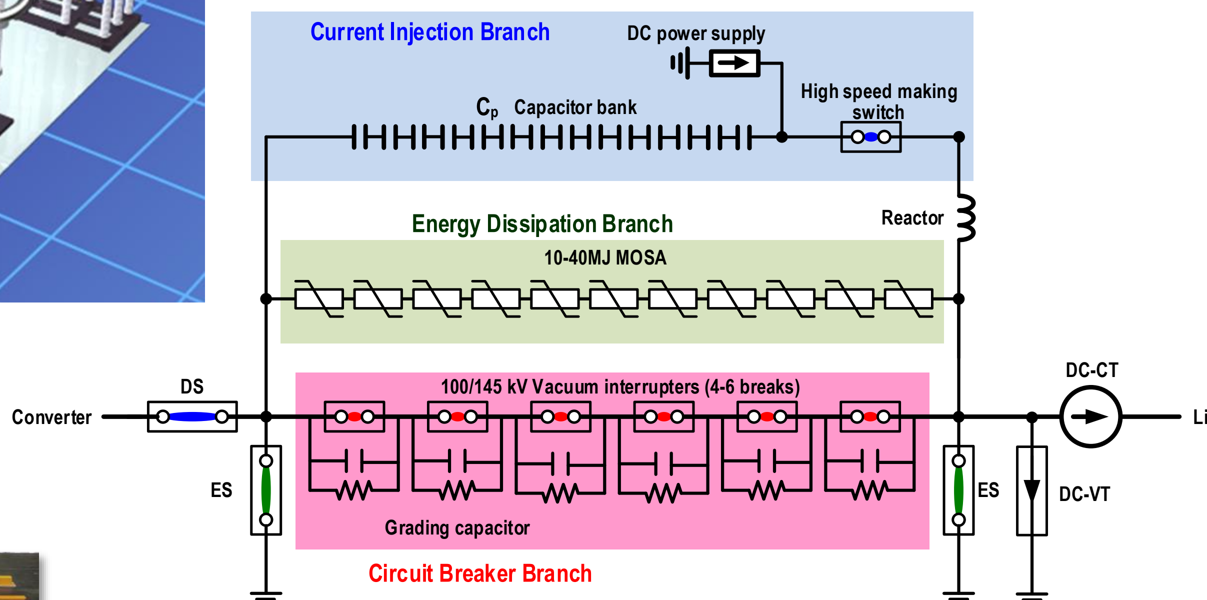
525/600 kV 16 kA DC circuit breaker



HVDC switchgear (switching equipment) composes of multi-break vacuum interrupters, multi-column MOSA units, a capacitor bank, high speed making switch and DC DS.

100-120kV Vacuum interrupter



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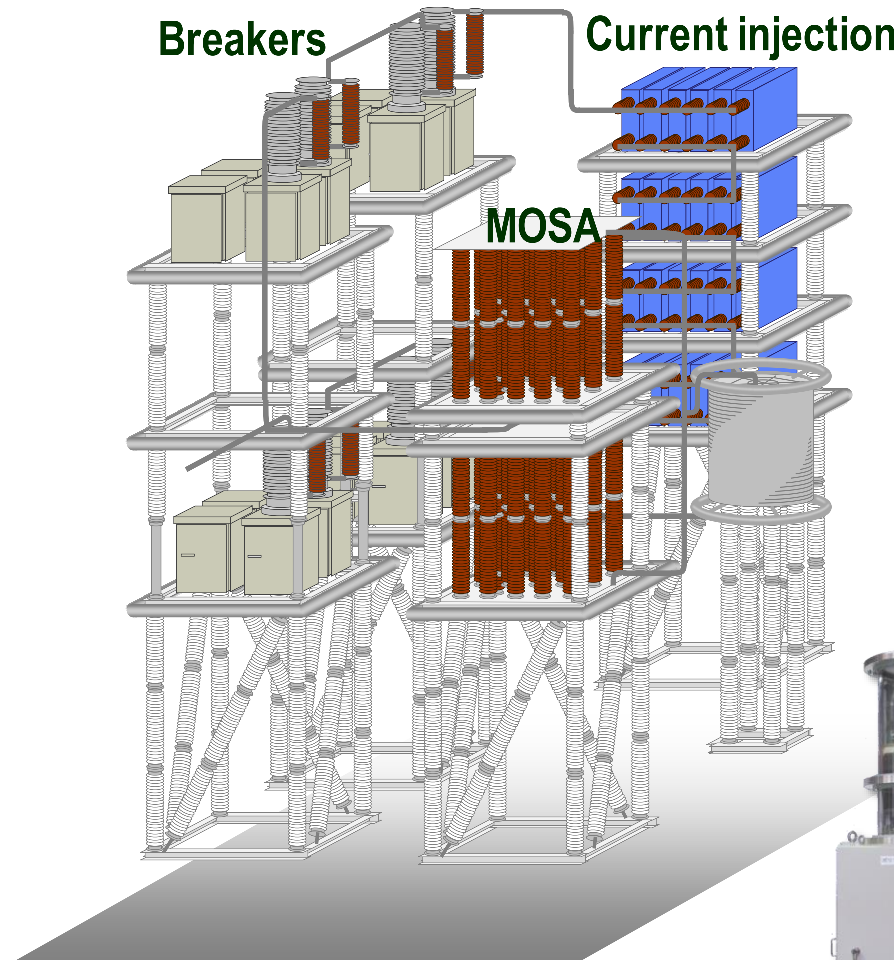
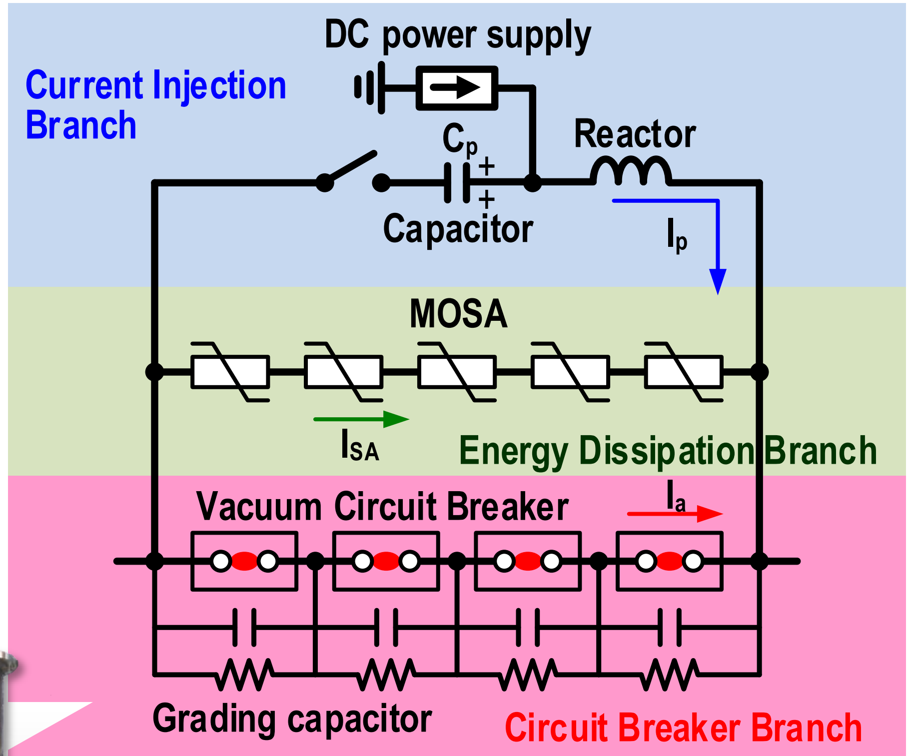
320/400 kV 16 kA DC circuit breaker





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HVDC circuit breaker demonstration at EU Promotion project

Triggered making gap

Auxiliary SF_6 AC CB

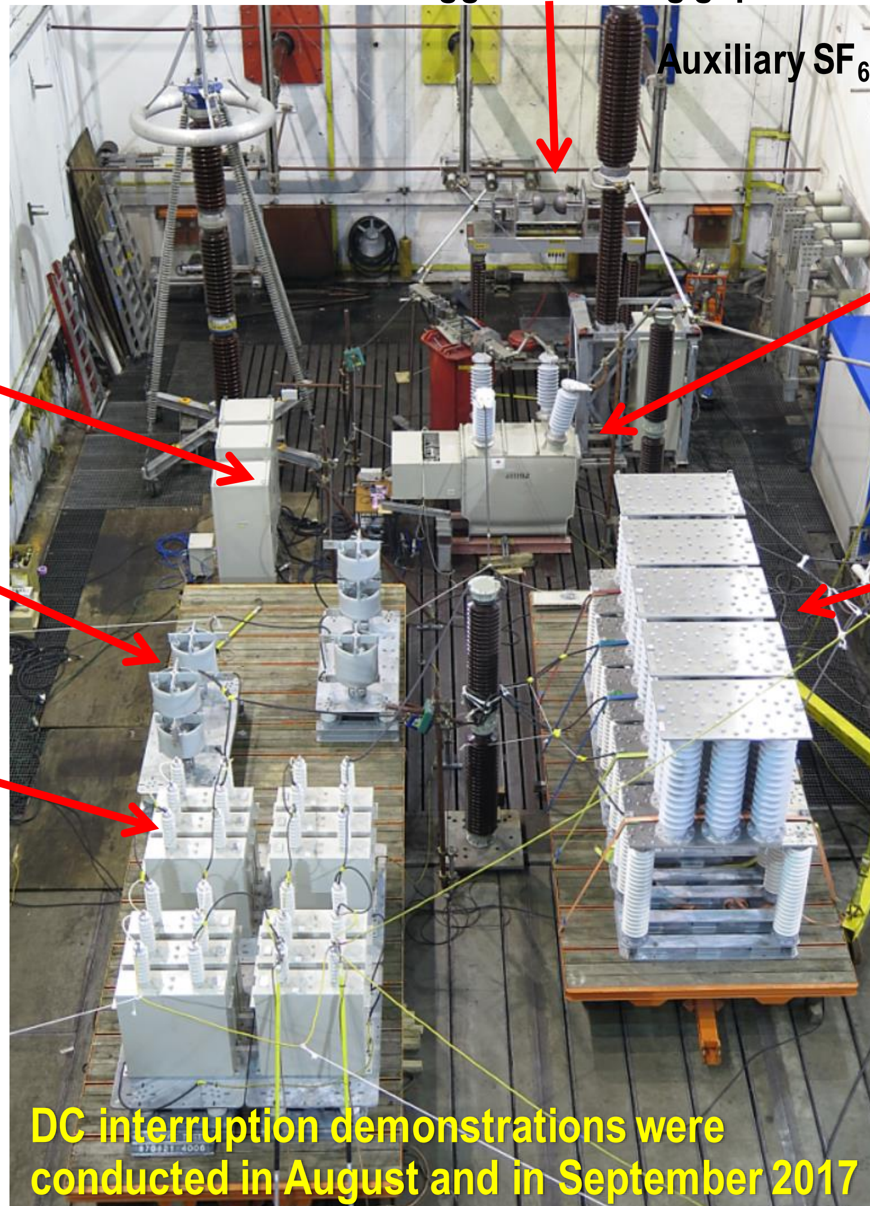
HV vacuum interrupter and making switch

DCCB Control Panel

Energy absorbing MOSA

Reactors

Counter current injection capacitors



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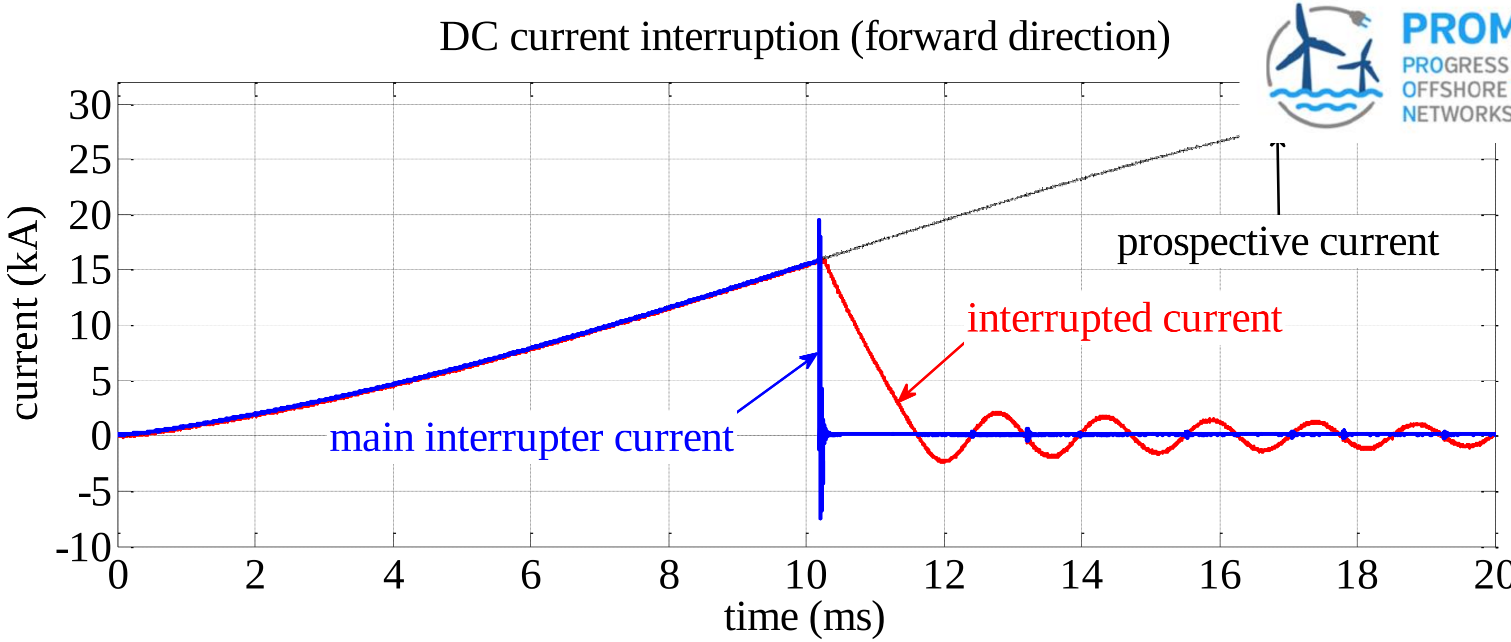
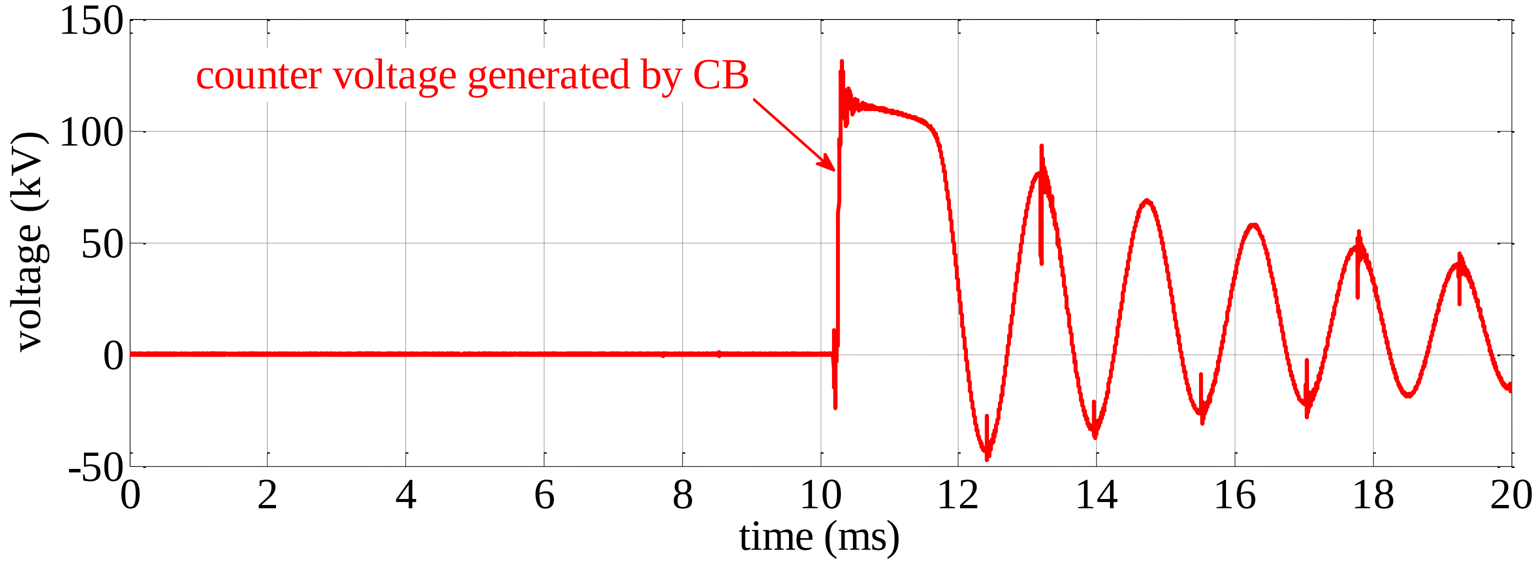
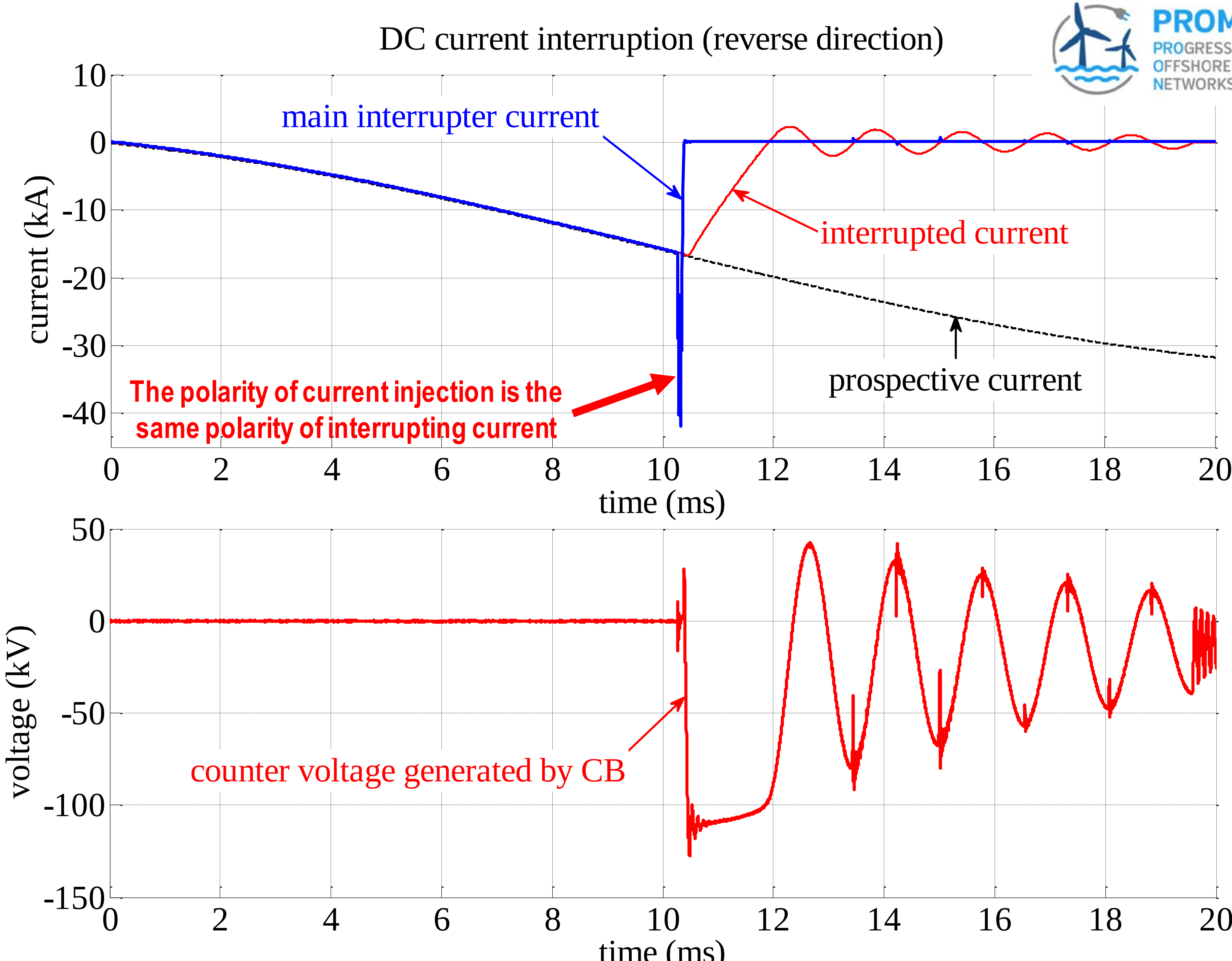
Test Results of HVDC CB at KEMA (16 kA)

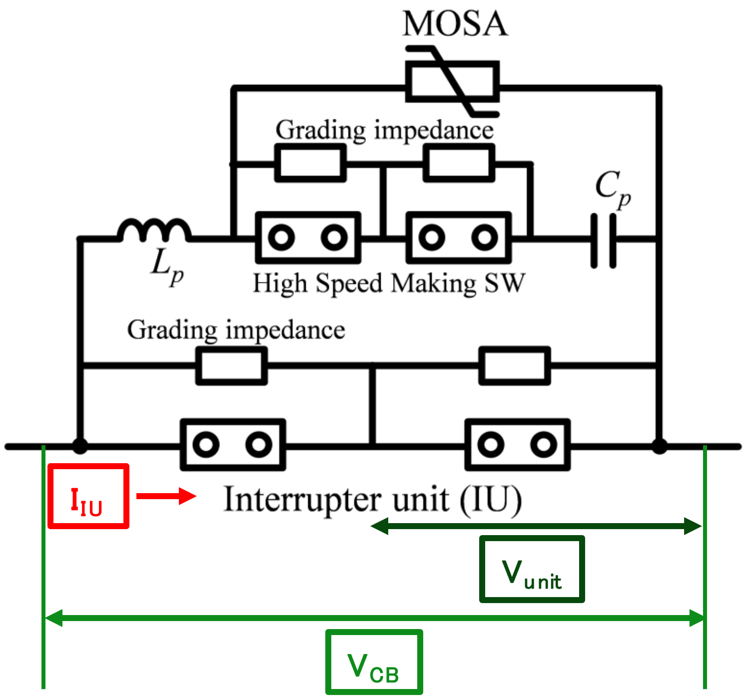




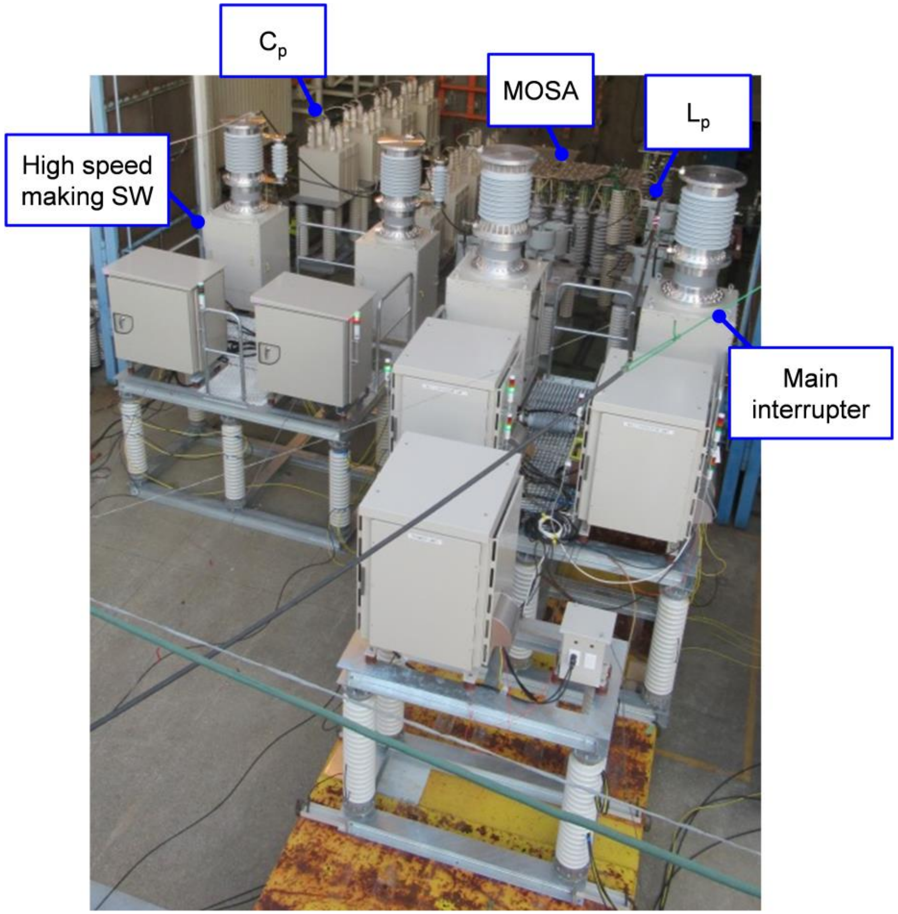
Test Results of HVDC CB at KEMA (-16 kA)



Testing setup in MELCO high power laboratory



Circuit diagram of double break mechanical DCCB with 200 kV rating



Testing setup

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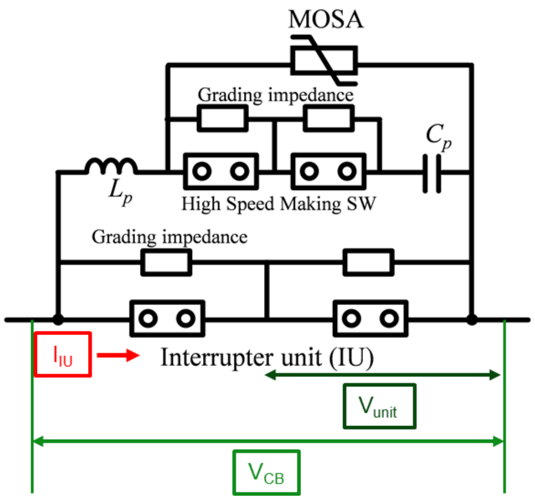
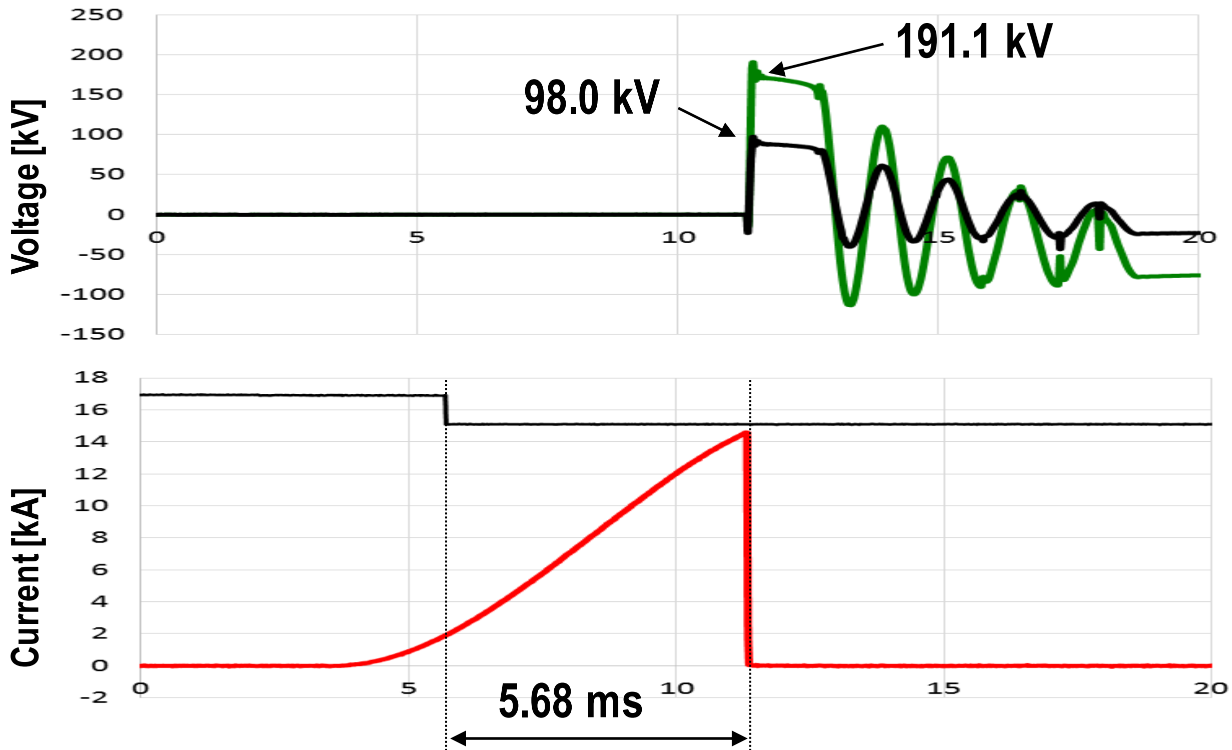
DCCB with double break vacuum interrupters



Circuit diagram of double break mechanical DCCB

- Interruption tests at DCCB voltage of 120 kV, 16 kA conditions have been operated using the mechanical HV CB with double break vacuum interrupters.
- TIV peak of 191 kV TIV (TRV) was successfully interrupted.
- The voltage sharing was confirmed to be as good as 51:49.



Typical waveform of current and voltage at the interruption test

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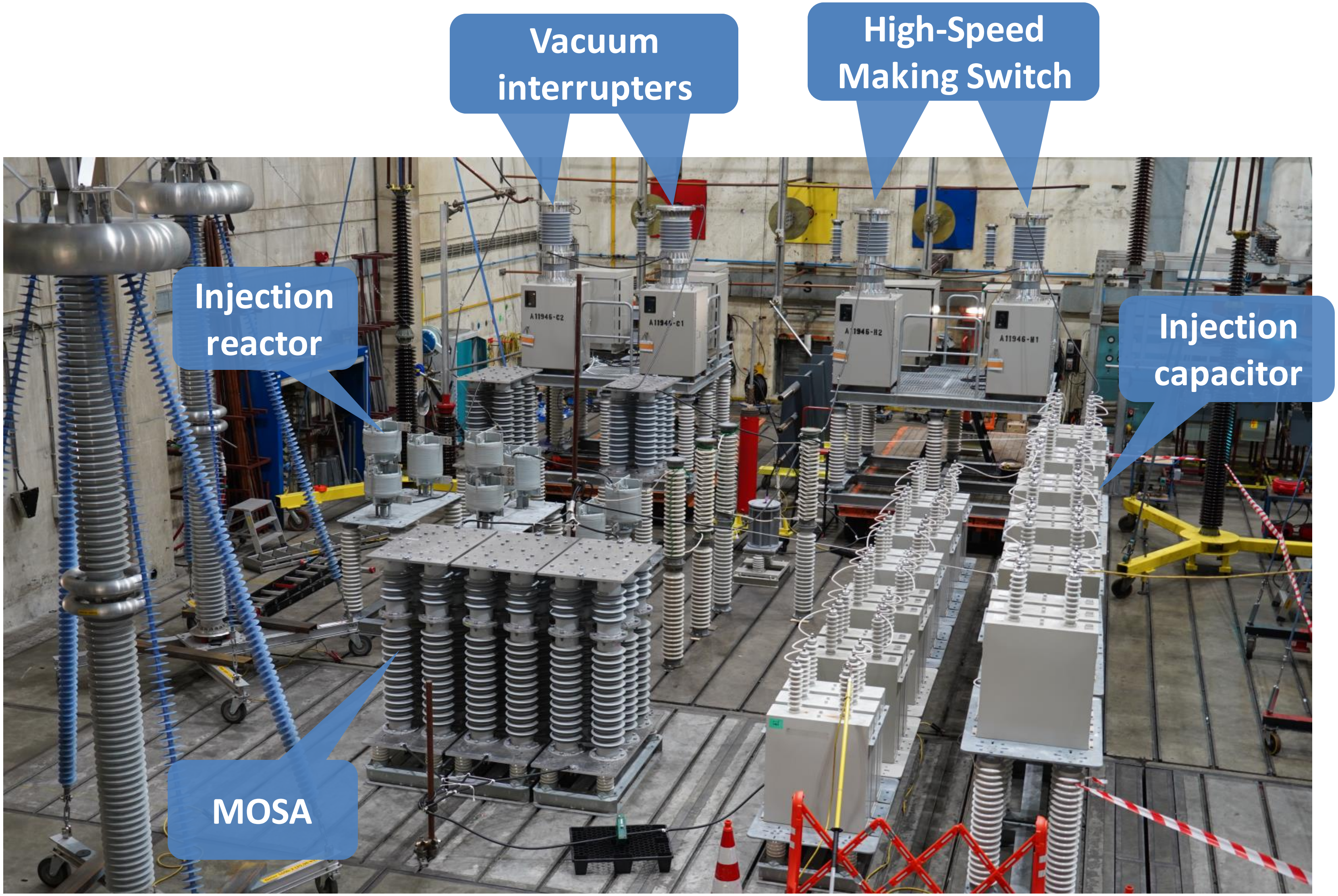
160/200 kV DCCB Testing Setup at KEMA



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Summary of DCCB tests

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Test results on Wednesday

Case	Test voltage (kV)	Test current (kA)	Breaker Operation Time (ms)	TIV Peak (kV)	MOSA (MJ)	Result
1	120	+8	7	+180	1	4 Successes
2	120	+16	7	+180	1.5	Success
3	160	+16	7	+250	2	2 Successes
4	160	-16	7	-250	2	2 Successes

Test Plan on Friday

Case	Test voltage (kV)	Test current (kA)	Breaker Operation Time (ms)	TIV Peak (kV)	MOSA (MJ)	Result
1	160	+16	7	+250 with RV	2	-
2	160	-16	7	-250 with RV	2	-
3	160	+2	7	+250 with RV	4	-
4	160	+0.1	7	+250 with RV	< 1	-
5	200	+16	7	+300	4	-

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Test Conditions of DCCB demonstration

Voltage	Current	TIV peak	MOSA energy
160 kV	+16 kA	+250 kV	4 MJ maximum
160 kV	-16 kA	-250 kV	4 MJ maximum

- TIV peak and MOSA energy will be varied depending on the test conditions.
- The maximum MOSA energy will be up to 4 MJ in order to test efficiently.

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Progress summary

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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 550/320 kV 16 kA ratings and above. MEU are ready for field installment of HVDC circuit breakers.

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