

Experiences of DC GIS installed in Kii HVDC Link

Commissioned in 2000

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Mitsubishi Electric Europe**

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TSO&DSO Utilities in Japan



Recent disasters in Japan

Why GIS in Japan?

Seismic intensity higher than 7 degree : 4
Seismic intensity higher than 6 degree : 26
Seismic intensity higher than 5 degree : 171
In the years of 2008-2018

M6.5 Earthquake
April 14, 2016
M7.3 Earthquake
April 16, 2016
Heavy rain
July 5, 2017

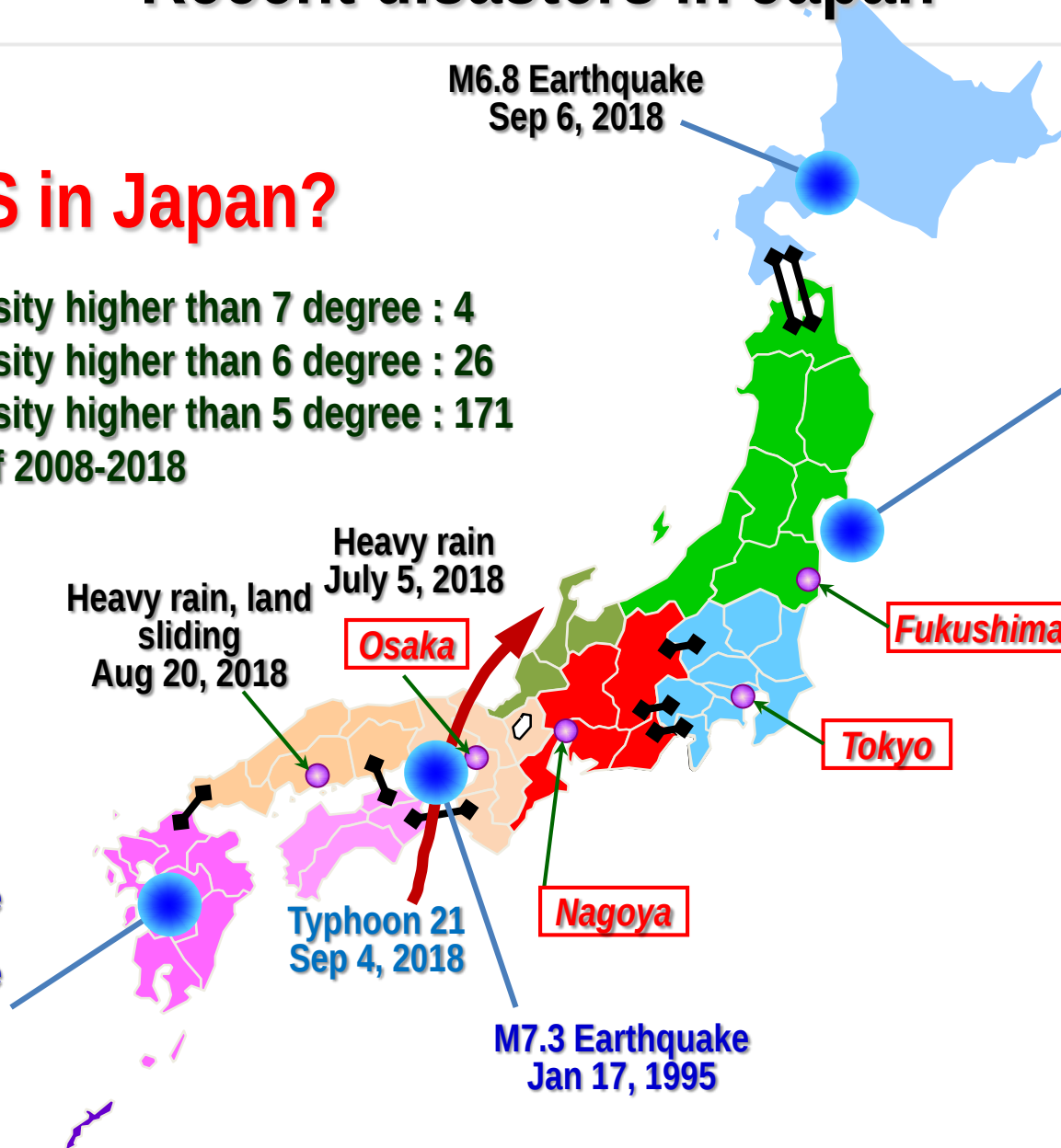
Heavy rain, land
sliding
Aug 20, 2018
Heavy rain
July 5, 2018

Typhoon 21
Sep 4, 2018

M6.8 Earthquake
Sep 6, 2018

M7.3 Earthquake
Jan 17, 1995

M7.9 Earthquake
March 11, 2011
M6.6 Earthquake
March 11, 2011
M7.4 Earthquake
April 7, 2011
M7.3 Earthquake
Dec 7, 2012



Contents

- Ø **Application of DC GIS in Kii-channel HVDC link, Japan**
- Ø **Necessity of DC GIS**
- Ø **Specification of Equipment in Kii-channel HVDC link**
- Ø **Switching Duties of DS for DC system**

Kii-Channel HVDC Link in Japan

+/-250/500 kV 1400 MW Kii-Channel HVDC link commissioned in 2000.

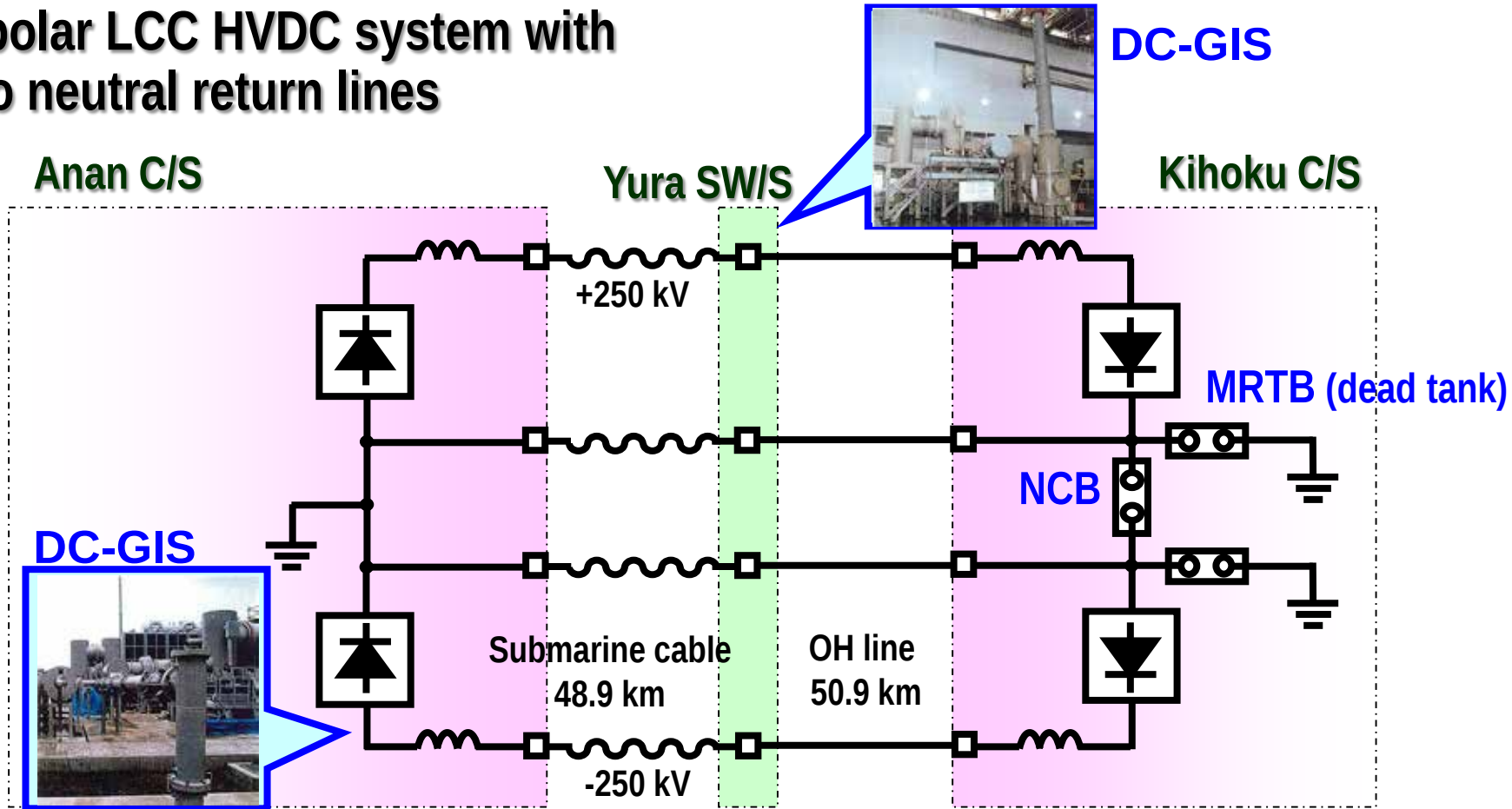
- Ø 2 converter stations
- Ø 1 switching station
- Ø Submarine cable: 49 km
- Ø Overhead line: 51 km



- Power Station
- Substation
- Switching Station
- Converter Station
- 500kV Overhead transmission Line
- 500kV Underground Transmission Line
- DC250kV Overhead Transmission Line (designed for 500kV)
- DC250kV Submarine Cable (designed for 500kV)

Kii-channel 250/500 kV bipolar HVDC Link

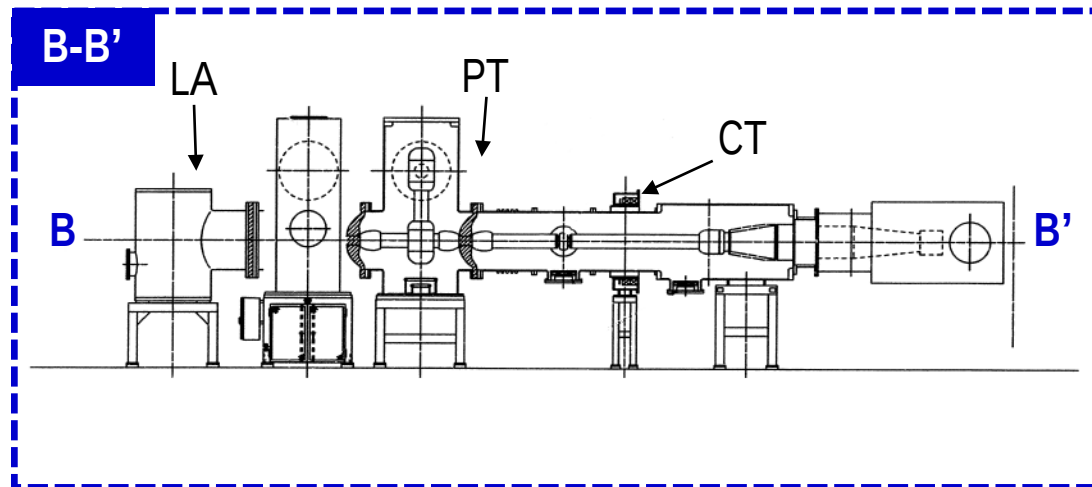
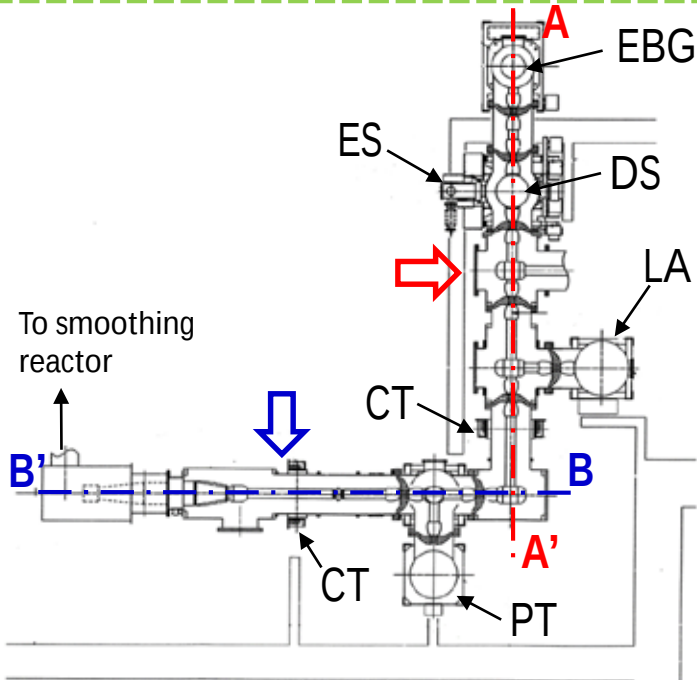
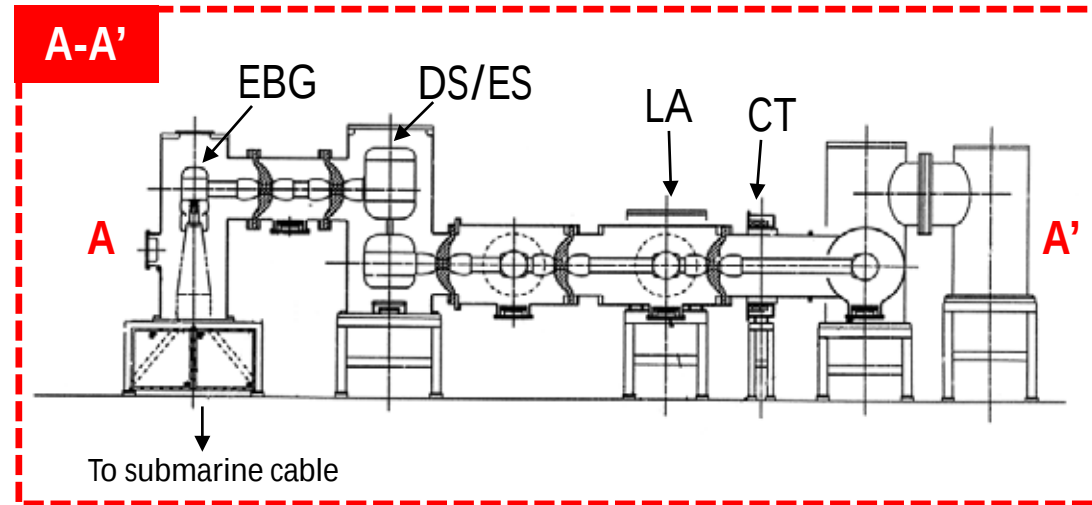
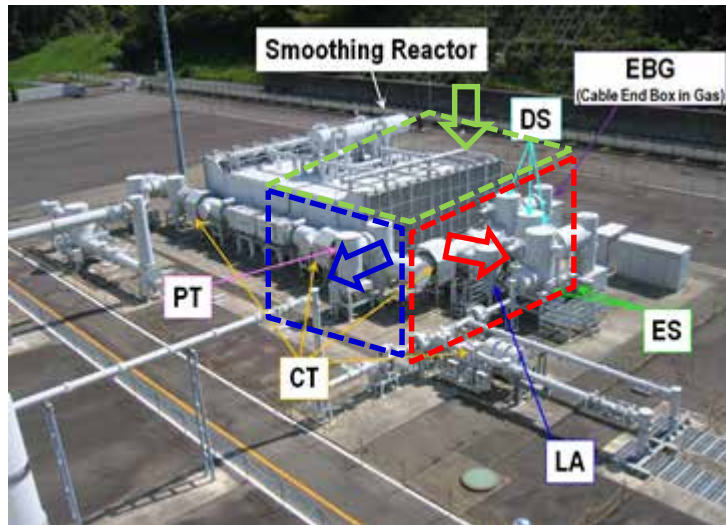
Bipolar LCC HVDC system with two neutral return lines



- Ø 500 kV DC GIS is installed at Anan C/S and Yura SW/S
- Ø All switching equipment and transmission lines (except for converters) are designed for use at DC 500 kV to enable build up transmission capacity in the future

MRTB: Metallic Return Transfer Breaker, NCB: Neutral Circuit Breaker,
C/S: Converter station, SW/S: Switching station, GIS: Gas Insulated Switchgear

DC 500 kV GIS installed at Anan C/S



DS: Disconnecting switch, ES: Earthing switch, LA: Surge arrester, CT: Current transformer, PT: Voltage transformer, EBG: Cable End Box in Gas

Purpose of DC GIS installation

DC GIS is required to cope with severe environmental requirements

Environmental requirements

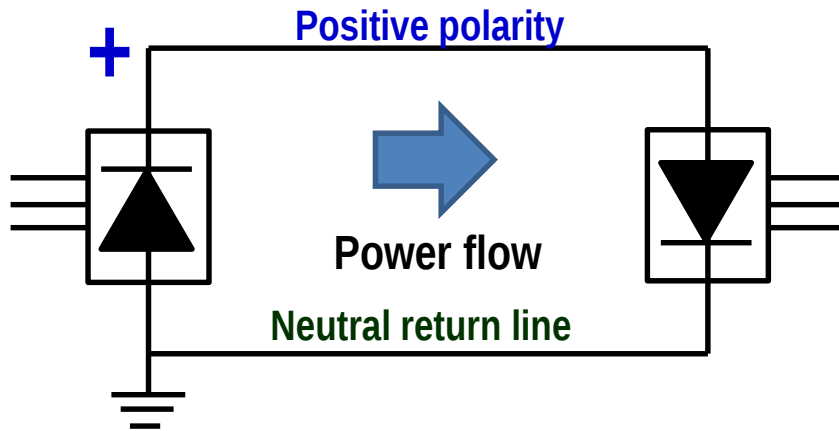
Heavy pollution environment near the coast requires higher salt-proof tolerance.

Frequent earthquake environment does not allow the application of porcelain bushing (still no standardization for polymer bushing at commissioning)

DC GIS requirements

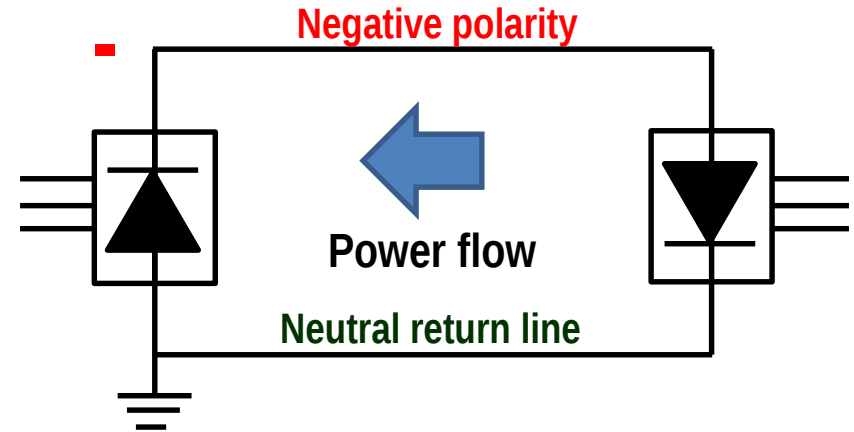
DC power system requires to change a power flow by polarity reversal. The polarity reversal can be conducted with the converters.

Normal operation



During transmission with either polarity, space charges will be accumulated near the electrode.

Polarity reversal

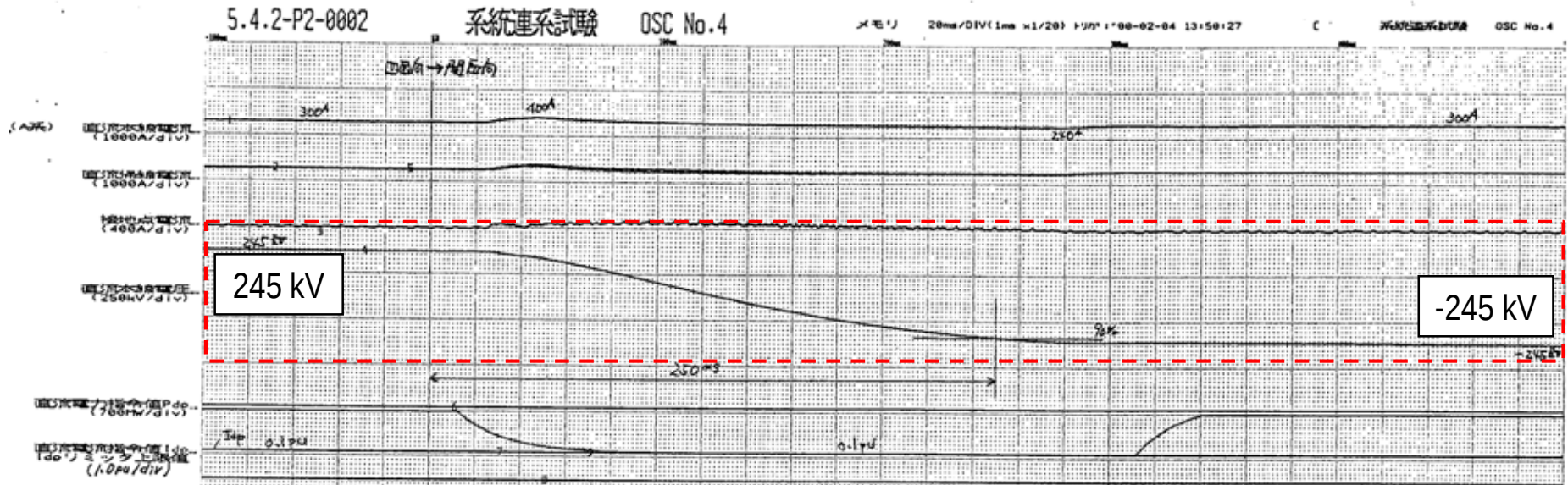


When the polarity is reversed, the space charge will affect the electric field resulting in higher voltage stresses on the insulator.

In conclusion, some redundancy of dielectric withstand is required for DC spacers considering the space charge influence in case of polarity reversal.

Demonstration of polarity reversal

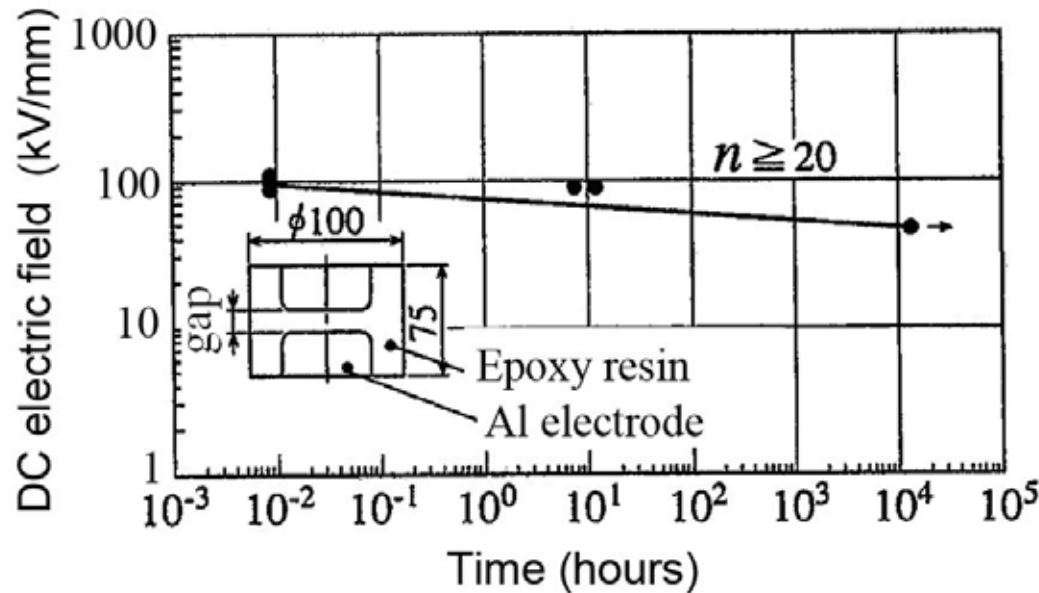
Polarity reversal operation of the converters during commission



The converter demonstrated to control the gate on-off timing of thyristor to change the output DC voltage from 245 kV to -245 kV in 250 ms.

DC-GIS dielectric design criteria

DC dielectric clearance requirements were determined by long-term DC V-t dielectric withstand tests using a epoxy resin specimen with application of DC ± 625 kV (1.25 E) for each 6 months. The index of DC dielectric withstand decay with time was evaluated as $n=20$ to estimate the requirement for the lifetime (30 years) from the results.



Test procedures

1) -625 kV for 6 months, 2) **Polarity reversal from -500 to 500 kV**, 3) +625 kV for 6 months, 4) **Polarity reversal from 500 to -500 kV**

Overvoltage test after long term test

After long-term DC ± 625 kV (1.25 E) voltage withstand test with DC-GIS on site, DC GIS prototypes were shipped back to the factory. Then DC voltage withstand tests were conducted to evaluate the insulation margin and the performance degradation with time. The prototype DC-GIS showed 1.2 time higher DC voltage withstand than the specification.

Requirements	Testing conditions	Results
Lightning impulse voltage	± 1560 kV (1300 kV $\times 1.2$), $1.2/50$ μ s, 3times	Passed
Switching impulse voltage	± 1410 kV (1175 kV $\times 1.2$), $250/2500$ μ s, 3times	Passed
DC voltage withstand	± 900 kV (750 kV $\times 1.2$) for 2 hrs, ± 1080 kV (900 kV $\times 1.2$) for 1 min, ± 900 kV (750 kV $\times 1.2$) for 2 hrs,	Passed
Polarity reversal	+750 kV (625 kV $\times 1.2$) for 2 hrs, follows -750 kV (625 kV $\times 1.2$) for 30 min -750 kV (625 kV $\times 1.2$) for 2 hrs, follows +750 kV (625 kV $\times 1.2$) for 30 min	Passed



Specifications of Equipment in Kii-channel HVDC link

Equipment	Rated voltage (kV)	Rated current (kA)	Rated short-time withstand current (kA)	DC withstand voltage (kV)	LIWV (kV)	SIWV (kV)	L.I. residual voltage (kV)
DC-GIS for main line	500	2.8 [3.5]	20 at 2sec	±900	1300	1175	N/A
DC-MOSA for main line	500	N/A	N/A	ditto	ditto	ditto	945 at 10 kA, 8/20 μs
MRTB for return line	10	3.5	20 at 2sec	N/A	400	350	N/A
NCB for neutral line	ditto	ditto	Ditto	N/A	ditto	ditto	N/A

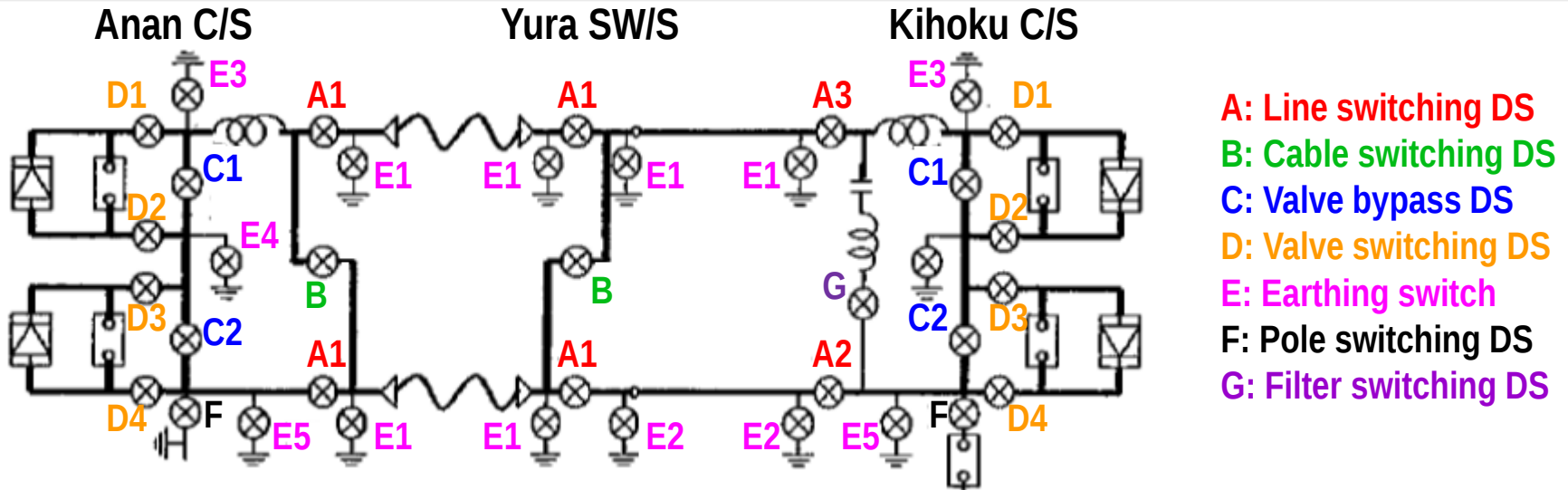
The value in [] is overload current at 30 min.

The rated short-time withstand current is set to 20 kA, 2 sec based on severe condition considering that AC side circuit breaker operates for backup when DC system is not under the control.

The rated voltage of MRTB and NCB is set to 10 kV considering DC voltage drop caused by metallic return line (1.5 ohm/line x 3.5 kA=5.25 kV).

The withstand voltage specifications of the equipment are determined based on the result of insulation coordination analysis using EMTP.

Switching Duties of DS for DC system



Switching duty	Applied DS	Detail of duty
Line discharge current switching duty	A1, A2, A3	Interruption of current which flows through snubber circuit in thyristor valve due to discharging residual charge of lines after converter is stopped.
No-load Line transfer current switching	B	Switch a no-load positive or negative transmission line to a neutral line, when a phase to ground fault occurred on the line. The system is stopped prior to DS operation.
Loop current switching duty	C1, C2	Interruption of loop current which flows at the time when converter starts or stops by a bank unit.
Charging current switching duty	D1, D2	Interruption of charging current which flows at the time when converter bank stops by a bank unit. This current includes ripple current from converter banks under operation.

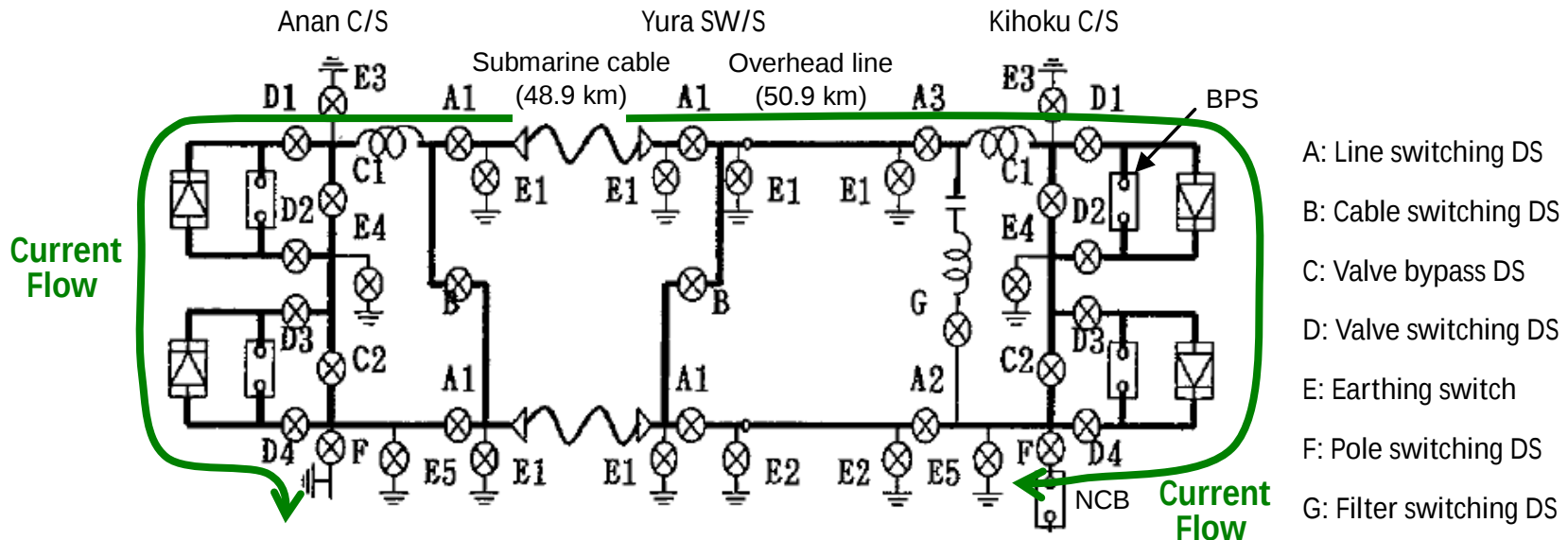
Group A: DC disconnecting switches

Group A1, A2, A3: Line discharging current switching duty

DS of group A1, A2, A3 are required to interrupt the line discharging current due to residual charges of the submarine cable.

The residual voltage induced in the line after a converter halt, is discharged through a snubber circuit in a converter bank at both C/Ss to the ground.

Discharge current: DC 0.1 A, Residual voltage: DC 125 kV

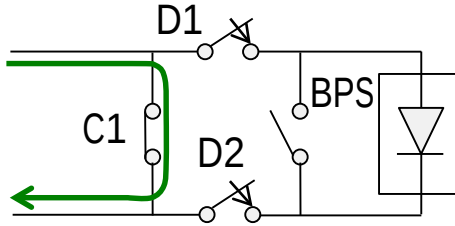


Group C, D: start & stop of converter banks

Start of converter bank unit

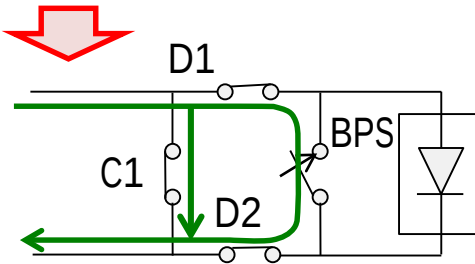
<Step1>

D1, D2 on



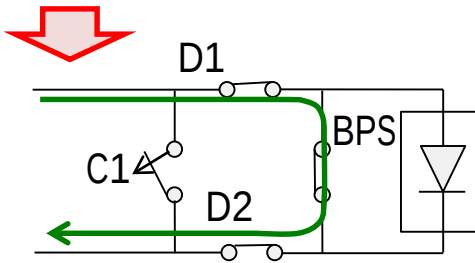
<Step2>

BPS on



<Step3>

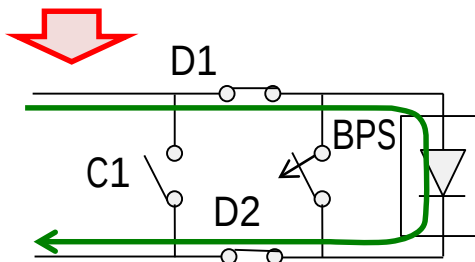
C1 off



Corresponding to "Loop current switching duty"

<Step4>

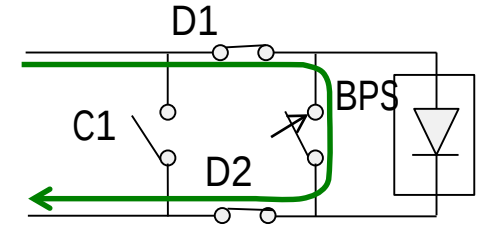
BPS off



Stop of converter bank unit

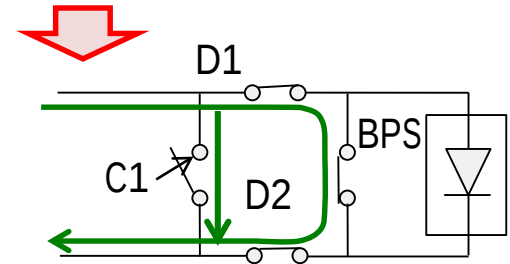
<Step1>

BPS on



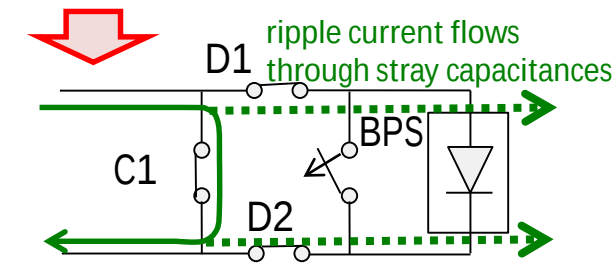
<Step2>

C1 on



<Step3>

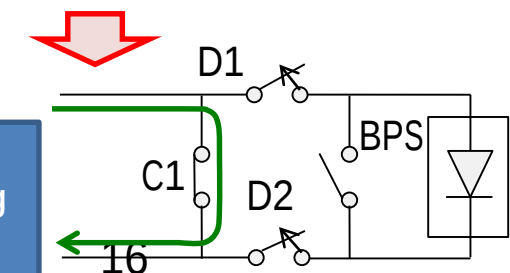
BPS off



<Step4>

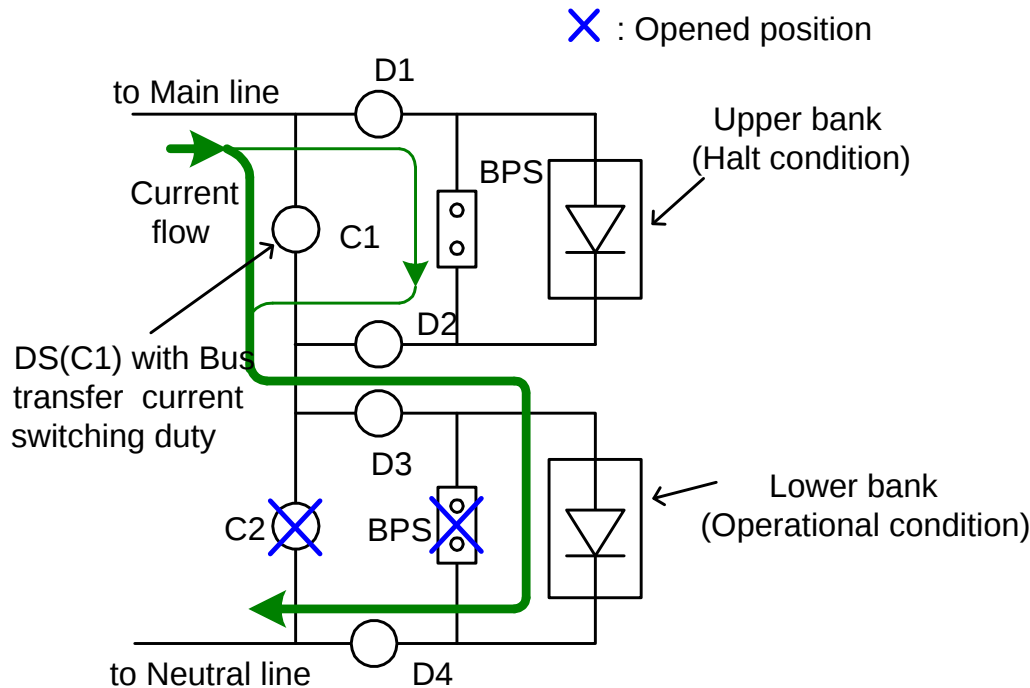
D1, D2 off

Corresponding to "Converter charging current switching duty"

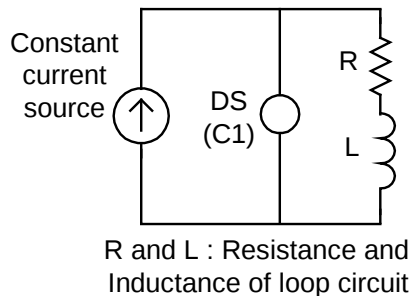
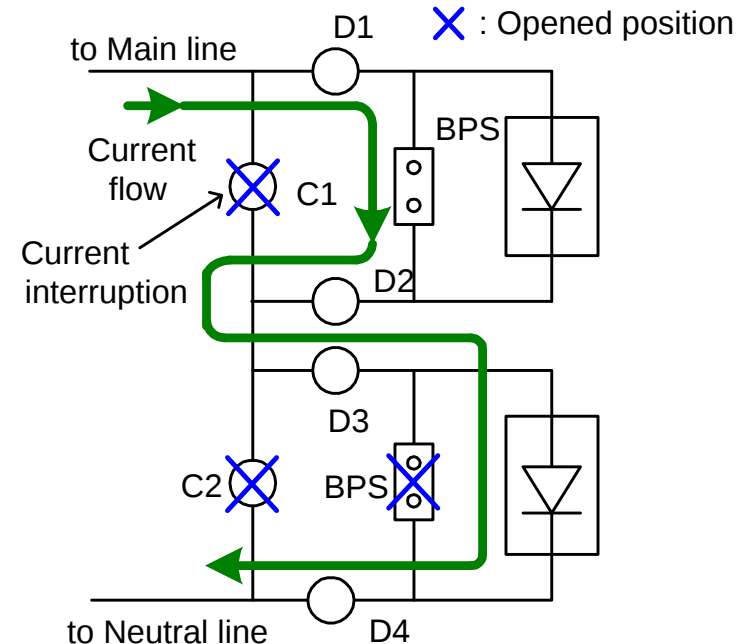


Group C: Loop Current Switching Duty

Before opening operation



After opening operation

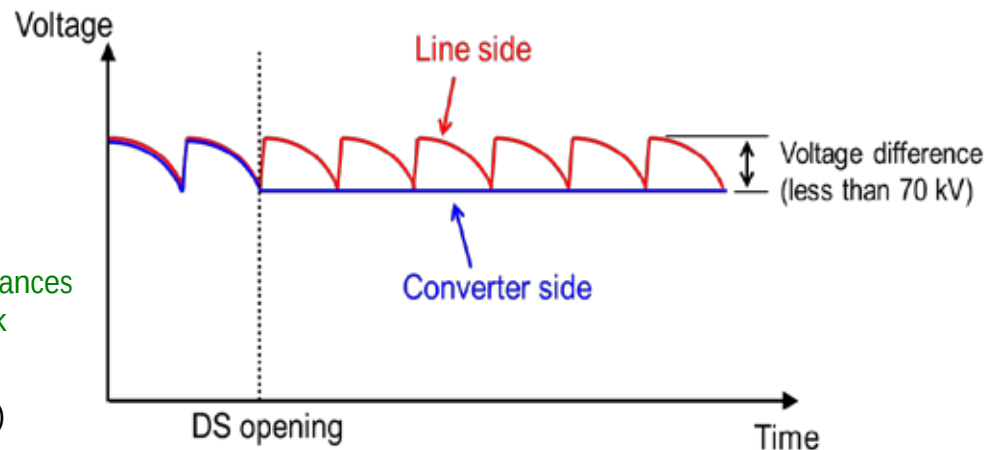


Based on the equivalent circuit of loop current interruption, a voltage of DC 1 V and a current of 2800 A were given as the switching test condition.

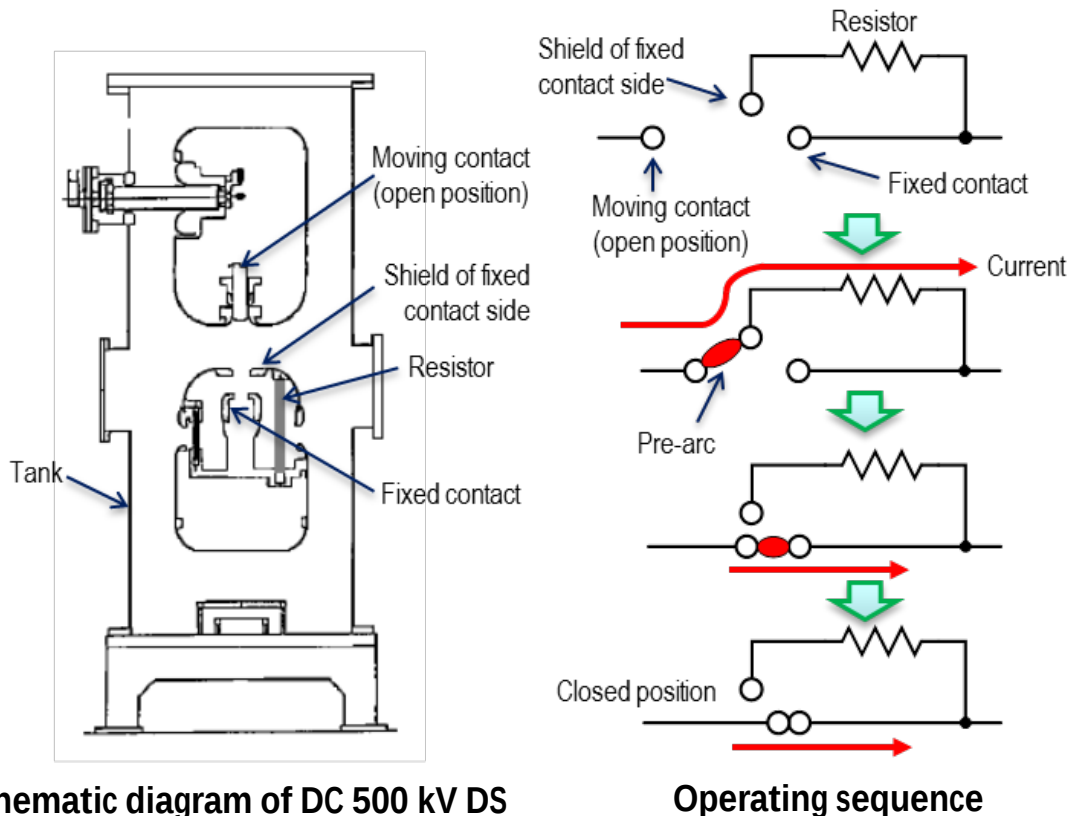
<Opening Requirements>

<Closing Requirements>

When a converter bank unit starts its operation, closing surge is generated by DS closing operation. In order to suppress this closing surge, closing resistor is equipped.



Group D: DC disconnecting switches



Schematic diagram of DC 500 kV DS
with closing resistor

Operating sequence

DS Group D is equipped with a closing resistor of 1 k Ω unit for suppression of the switching surge. In the process of the closing operation, pre-arc is generated between the moving contact and shield of fixed contact side at first. The arc is commutated to the fixed contact from the shield when the moving contact approaches to the fixed contact than the shield. The purpose of applying this resistor is to suppress the closing surge, however, a resistor is also inserted in case of opening sequence due to the structure of DS.

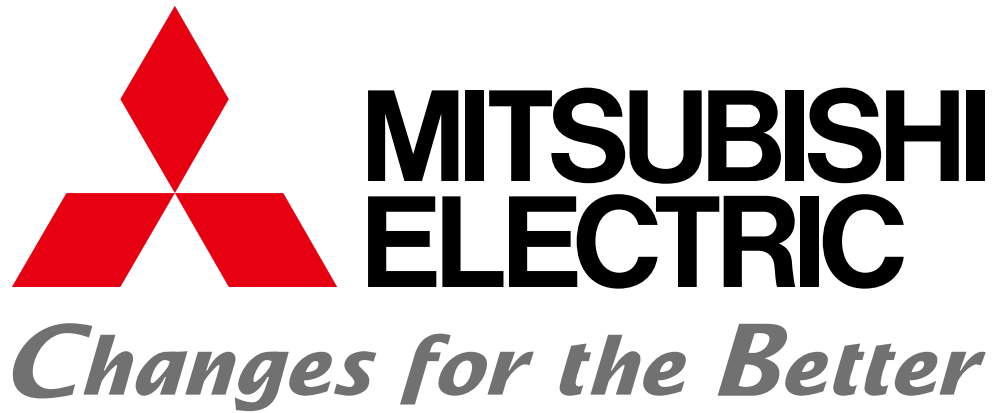
Summary

Kii-Channel HVDC link (± 250 kV, 1400 MW) transmits electricity from Shikoku Island to Kansai area, since it commissioned in 2000.

DC-GIS in Kii-Channel HVDC link is designed to endure the DC voltage of 500 kV with some redundancy, considering polarity reversal.

DC-DS and ES has a similar design with AC-DS and ES with some dielectric redundancy.

DC-GIS is more reliable and economical, rather than constructing the substation with air insulated equipment to satisfy severe Japanese environmental conditions.

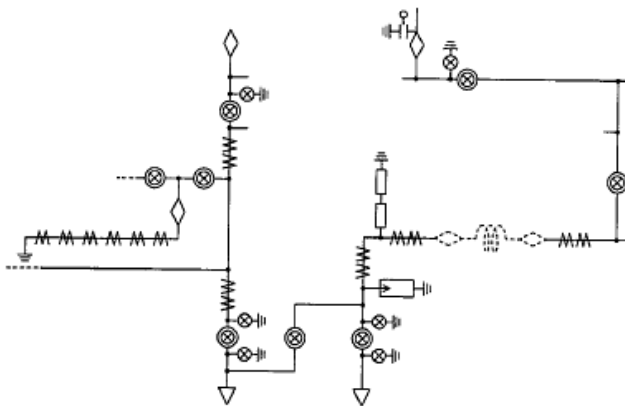


Long-term DC voltage withstand test of DC 500 kV GIS



Long-term test for one year in the Yamazaki Experiment Center.

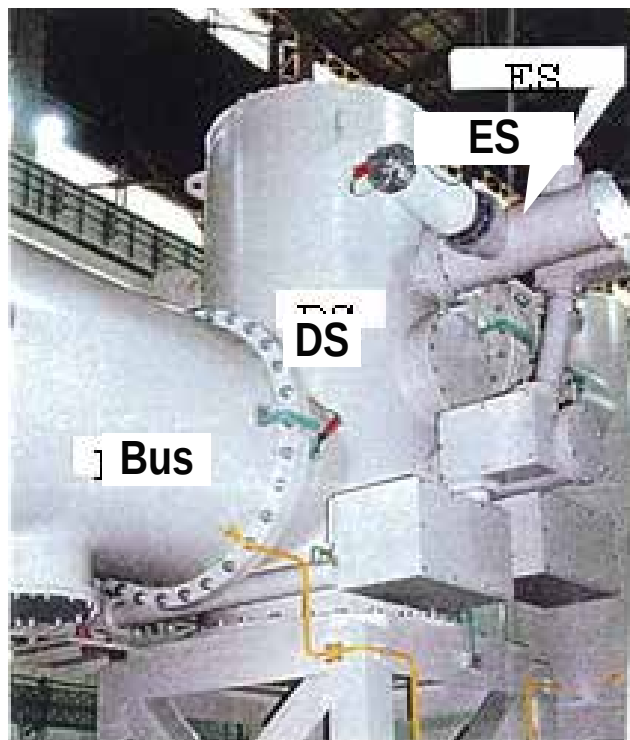
HVDC GIS in Japan



DC GIS installed at Anan conversion station

Rated Voltage	+/-500 kV
Lightning impulse withstand voltage	+/-1300 kV
Switching impulse withstand voltage	+/-1175 kV
AC withstand voltage	559 kVrms (30 min) >> 645 kVrms (5 min) >> 559 kVrms (30 min)
DC withstand voltage	+/-750 kV (2 h) >> +/-900 kV (1 min) >> +/-750 kV (2 h)
Polarity reversal withstand voltage (Polarity reversal time is within 1 min.)	+625kV (2 h) >> -625 kV (30 min) and -625kV (2 h) >> +625 kV (30 min)

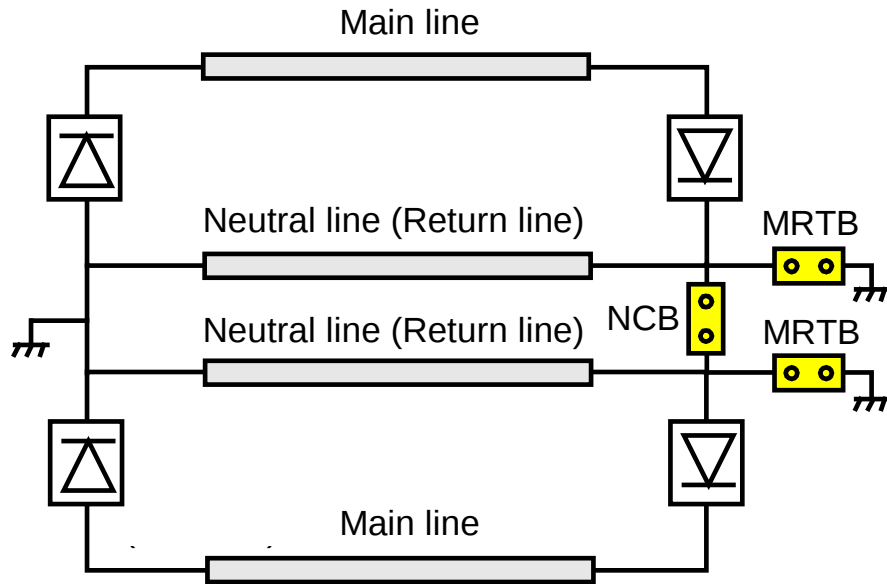
Appearance and specifications of DC DS



Rated voltage	500 kV
Rated current	2800 A, [3500 A]
Rated short-time withstand current	20 kA, 2 sec.
Lightning impulse withstand voltage	1300 kV
Switching impulse withstand voltage	1175 kV
DC withstand voltage	+/- 900 kV
Power-frequency withstand voltage	645 kV rms
Polarity reversal voltage	+/- 625 kV

The value in [] is overload current at 30 min.

Transfer Switching Switches

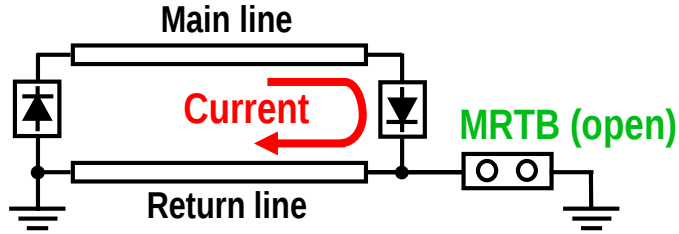


MRTB is normally opening state and it is closed when fault occurs in return line. After extinction of the fault arc, MRTB interrupts and commutates DC current to the return line.

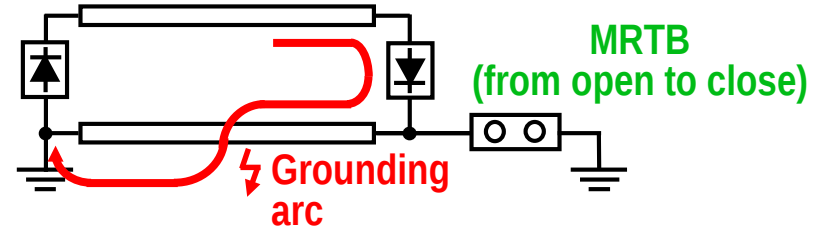
NCB is normally closing state and it interrupts DC current when converter operation switches from bipolar operation to monopolar operation.

Equipment	Rated voltage (kV)	Rated current (kA)	Rated short-time withstand current (kA)	DC withstand voltage (kV)	LIWV (kV)	SIWV (kV)	L.I. residual voltage (kV)
MRTB for return line	10	3.5	20 at 2sec.	N/A	400	350	N/A
NCB for neutral line	ditto	ditto	Ditto	N/A	ditto	ditto	N/A

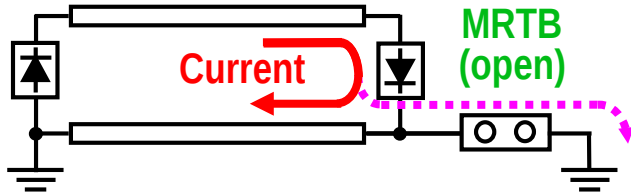
Operating Sequence of MRTB



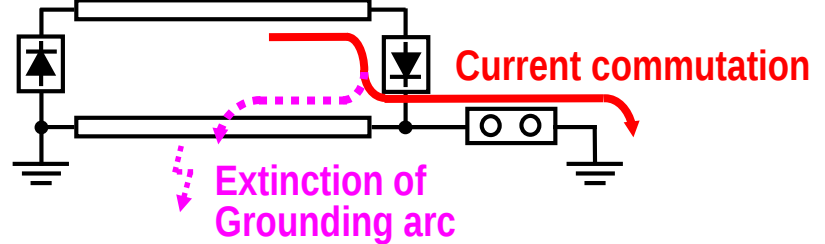
(1) Normal operation



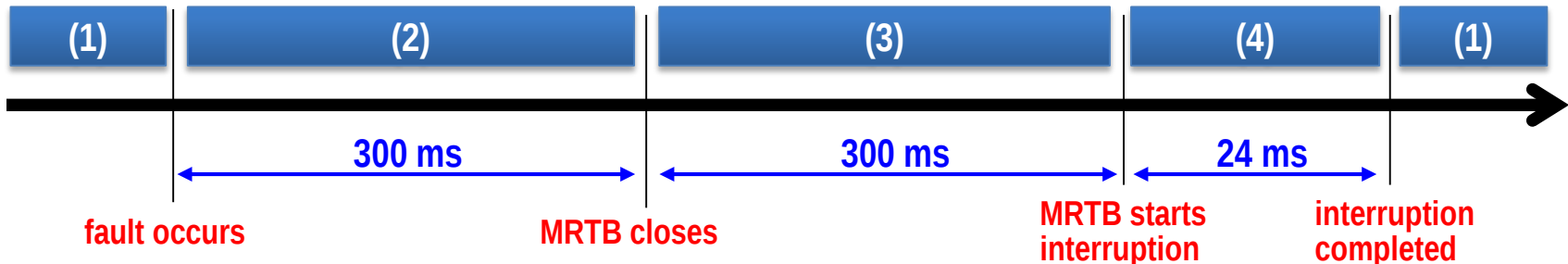
(2) When a fault occurs in a return line, the MRTB closes



(3) Fault current is commutated to the MRTB and the grounding arc is extinguished



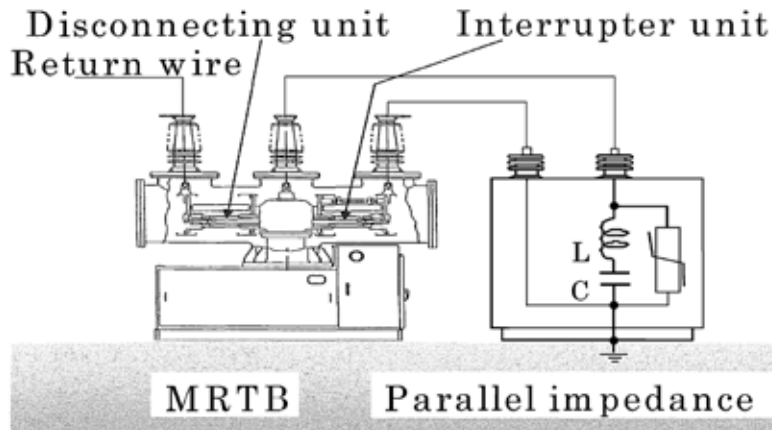
(4) MRTB interrupts and commutates DC current to the return circuit



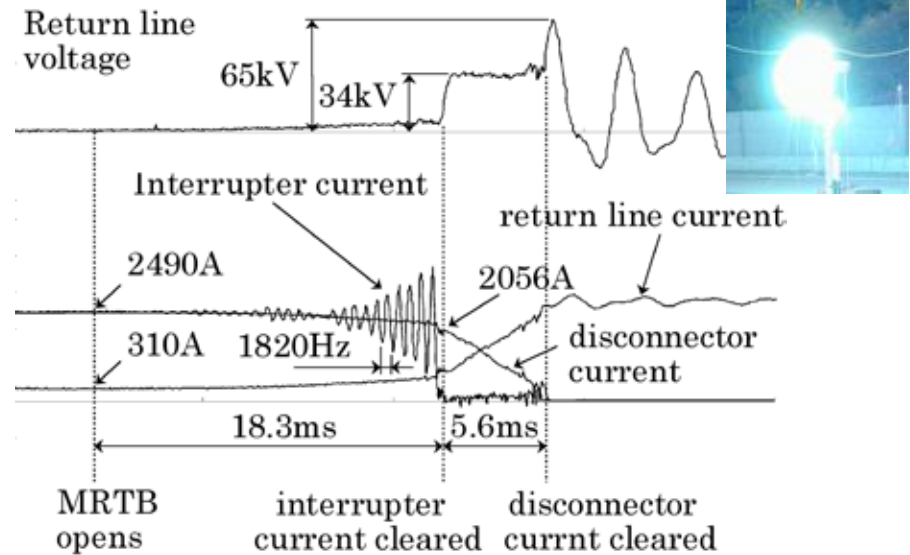
MRTB artificial grounding test



Appearance and configuration of MRTB



Artificial grounding DC current interruption by MRTB



It was confirmed in artificial grounding test in return line that the protection relay detected the fault and the return line recovered from fault condition by closing and interrupting operation of MRTB.

DC 500 kV GIS installed at Anan C/S

