

Status and Trends of HVDC

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HVDC and Power Electronics

TGS™
TransGrid Solutions

ELECTRICITY SUPPLY SYSTEMS OF THE FUTURE

INTERNATIONAL COUNCIL
ON LARGE ELECTRIC SYSTEMS

The purpose of modern power systems is to supply electric energy satisfying the following conflicting requirements:

- High reliability and security of supply
- Most economic solution
- Best environmental protection

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3 INTEGRATION OF HVDC / POWER ELECTRONICS (PE)

Key Challenges

- Integration of multi-infeed HVDC networks in the AC network
- Effects of PE penetration at all voltage levels
- Need for appropriate models for HVDC and PE systems for network performance studies.
- Fault recovery of HVDC networks
- Standards and Grid Codes for HVDC grids to enable gradual system development ensuring compatibility among different converter manufacturers.

No	WG	Description	Convenor
1	WG B4.64	Impact of AC System Characteristics on the Performance of HVDC schemes	Jef Beerten
2	WG B4.66	Implications for harmonics and filtering of the installation of HVDC converter stations in proximate locations	Fernando Cattan
3	WG B4.67	Harmonic aspects of VSC HVDC, and appropriate harmonic limits	Nigel Shore
4	WG B4.68	Revision of Technical Brochure 92 – DC Harmonics and Filtering	Nigel Shore
5	JWG C4/B4.38	Network Modelling for Harmonic Studies	Marta Val Escudero
6	WG B4.69	Minimizing loss of transmitted power by VSC during	Dennis Woodford
7	WG B4.70	Guide for Electromagnetic Transient Studies involving VSC converters	Dennetiere Sébastien
8	WG B4.71	Application guide for the insulation coordination of Voltage Source Converter HVDC (VSC HVDC) stations	Mojtaba Mohaddes
9	WG B4.72	DC grid benchmark models for system studies	Ting An
10	JWG B4/B1/C4.73	Surge and extended overvoltage testing of HVDC Cable Systems	Markus Saltzer
11	WG B4.74	Guide to Develop Real Time Simulation Models (RTSM) for HVDC Operational Studies	Qi Guo
12	WG B4.75	Feasibility Study for assessment of lab losses measurement of VSC valves	Christian Rathke
13	WG B4.76	DC/DC converters in HVDC Grids and for connections to HVDC systems	Dragan Jovcic

No	WG	Description	Convenor
14	TF B4.77	AC fault response options for VSC HVDC converters	John Gleadow
15	WG B4.78	Cyber Assett Management for HVDC/FACTS Systems	Kerry Walker

VSM

Cigre Task Force B4.77

Part of the perceived need of the TSO is not only to have a large reactive fault current but also, to be able to deliver this rapidly in response to an AC system fault. This is referred to as FFCI (Fast Fault Current Injection). The perception is that present day VSC controllers, which act to control the current seen by the power electronic converters, are not sufficiently fast enough to meet the future AC grid needs. A second perceived problem with FFCI requirement is that it can create temporary overvoltages following ac fault clearing in low short circuit level grid conditions.

Changing the fault response of a HVDC converter, considering FFCI, specifying fault currents greater than the converters active power rating, or even adopting a VSM type control concept will have an impact on both the converter hardware design, its rating, its losses and the effective utilisation of the capital investment by the owner.

HVDC OVERVIEW

Role of HVDC

- Long distance transmission
- Asynchronous system inter-connections
- Enhanced power system operation
- Integration of renewable generation

Copyright: Siemens
And Infineon

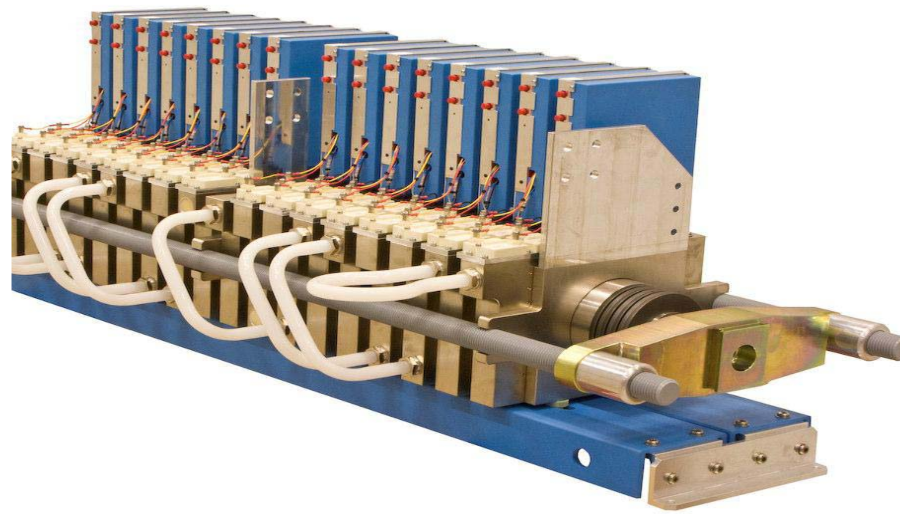
Two Parallel Technology Paths

- Mature and Growing Thyristor based LCC HVDC
- Developing and Growing IGBT VSC HVDC

Copyright: Siemens

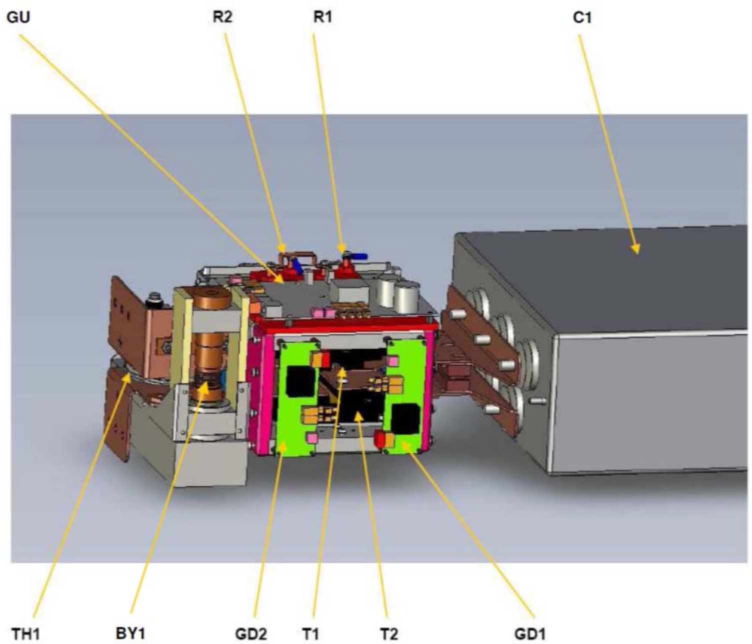
HVDC Present

Lund Symposium paper 125

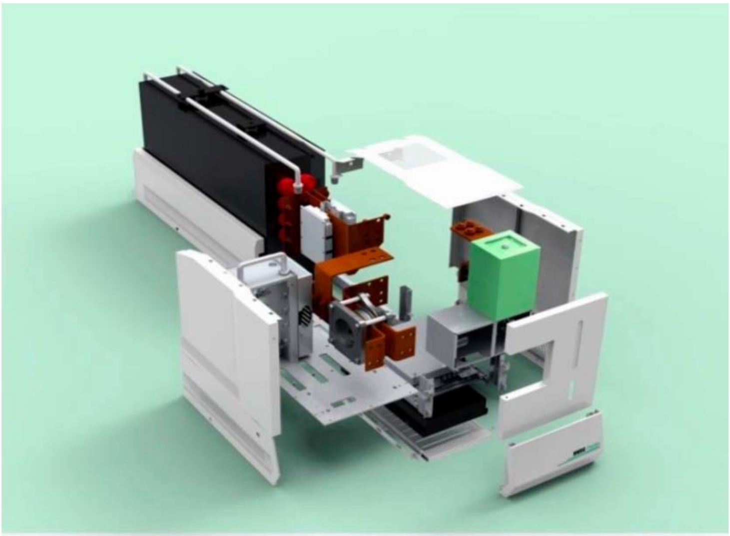


Courtesy of ABB

HVDC



Courtesy of Siemens



Courtesy of State Grid

HVDC

Location	Biswanath Chariali, Alipurduar, Agra
Power Rating	6000MW
DC voltage	±800kV
AC voltage	400kV
Length	1728km
	Ground electrodes

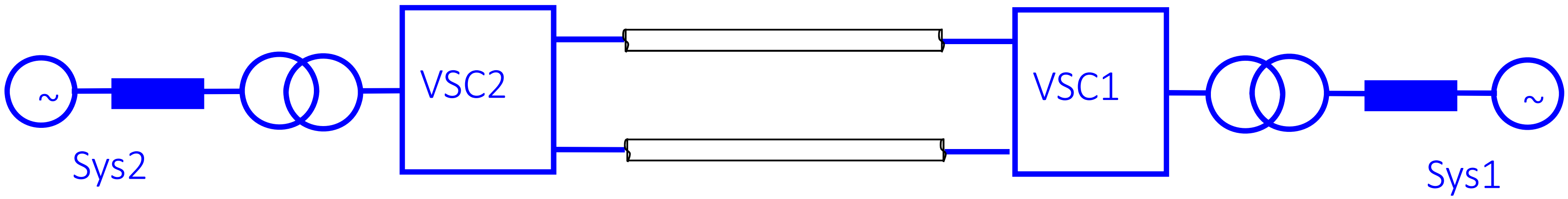
Courtesy of ABB and Power Grid of India

HVDC TECHNOLOGIES KEY PARAMETERS COMPARISON

Technology	Line Commutated Converter (LCC)	Voltage Sourced Converters (VSC)
Semiconductor	Thyristor (Turn on only)	IGBT (Turn on/off)
Ratings	High DC Voltage and Power	Lower DC Voltage &Power
Power Control	Active Power	Active & Reactive Power
AC Filters	Required	Not Required (MMC)
Minimum SCR	>2	0
Black Start Capability	No	Yes
Overload	High inherent overload capabilities	Normally not unless specified
Footprint	Larger site (More space required for harmonic filters)	Compact, 50-60% of LCC
Configurations	Monopole, Bipole	Symmetric Monopole,, Bipole, Multi-terminal
Application	Point-to-Point, Back-to-Back Multi-terminal	Point-to-Point, Back-to-Back Multi-terminal, HVDC Grid

VSC Application

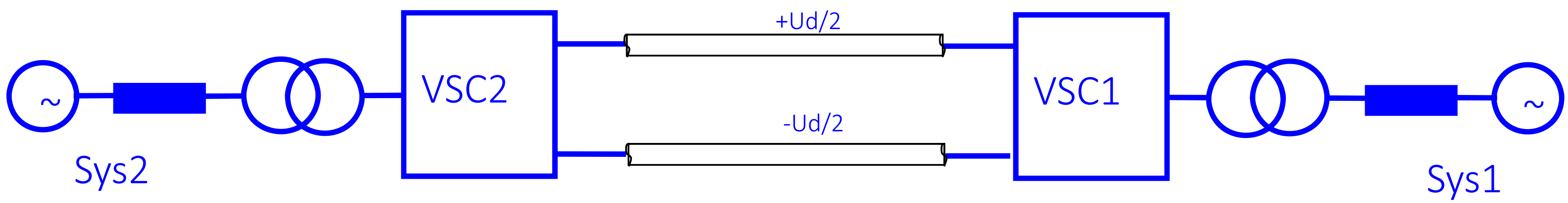
HVDC Transmission



- Similar to conventional HVDC, one station controls DC current and one station controls DC voltage
- Power reversal is through change of DC current direction, DC voltage polarity remains unchanged
- Reactive power is controlled independently at each terminal
- Can use XPLE cables (available up to 525kV)

VSC-HVDC Transmission

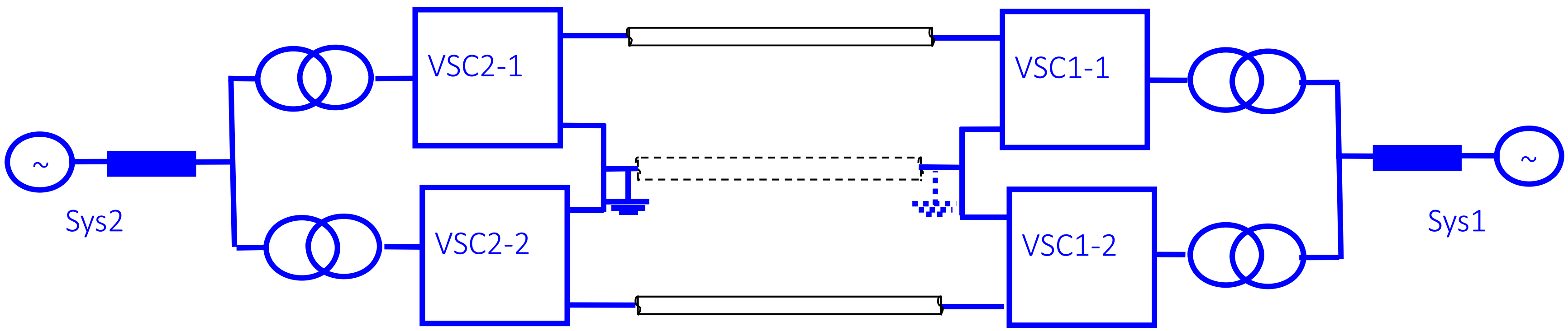
Symmetrical Monopole Configuration



- Regular AC transformer
- Dc to ground fault does not cause high short circuit current
- Uses two high voltage cables, each rated for Ud/2
- Can be realized with half bridge converters without extra equipment
- No power transfer capability with a monopole outage

VSC – HVDC Transmission

Bipolar Configuration

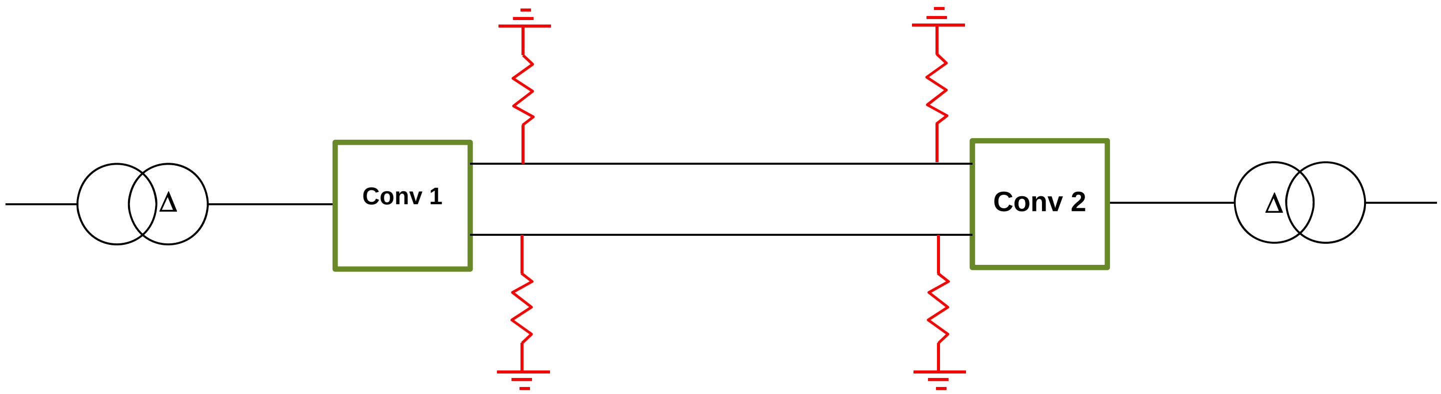


- Can have ground or metallic return
- Converter transformer (dc stress on secondary windings)
- Dc to ground fault cause high short circuit current affecting ac systems (worse than LCC)
- Uses two high voltage conductors and possibly one low voltage conductor
- Can be realized with half bridge or full bridge converters, in case of HB requires extra equipment for dc and ac fault
- 50% (or more) power transfer capability with a monopole outage

Symmetrical Monopole

Ground Reference

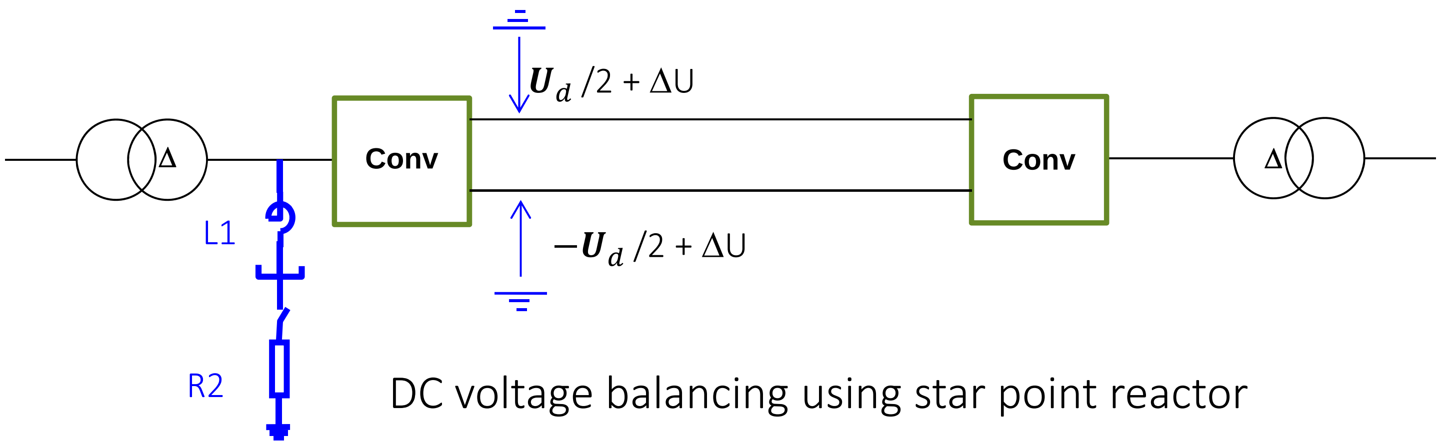
In symmetrical monopole configuration dc circuit is floating and therefore can drift.



using voltage divider resistors to prevent DC Voltage shifting

Symmetrical Monopole

Ground Reference



DC voltage balancing using star point reactor

- Required only at one station (except for STATCOM operation with DC cable disconnected) to avoid zero sequence current (mainly 3rd harmonic) circulation between stations
- Under normal conditions current in L1 is negligible (L1>>)
- The voltage across R2 is equal to ΔU
- Stresses during dc line to ground fault should be considered in selection of R2

Fault Performance

Pole to ground fault in symmetrical monopole with HB (no dc breaker)

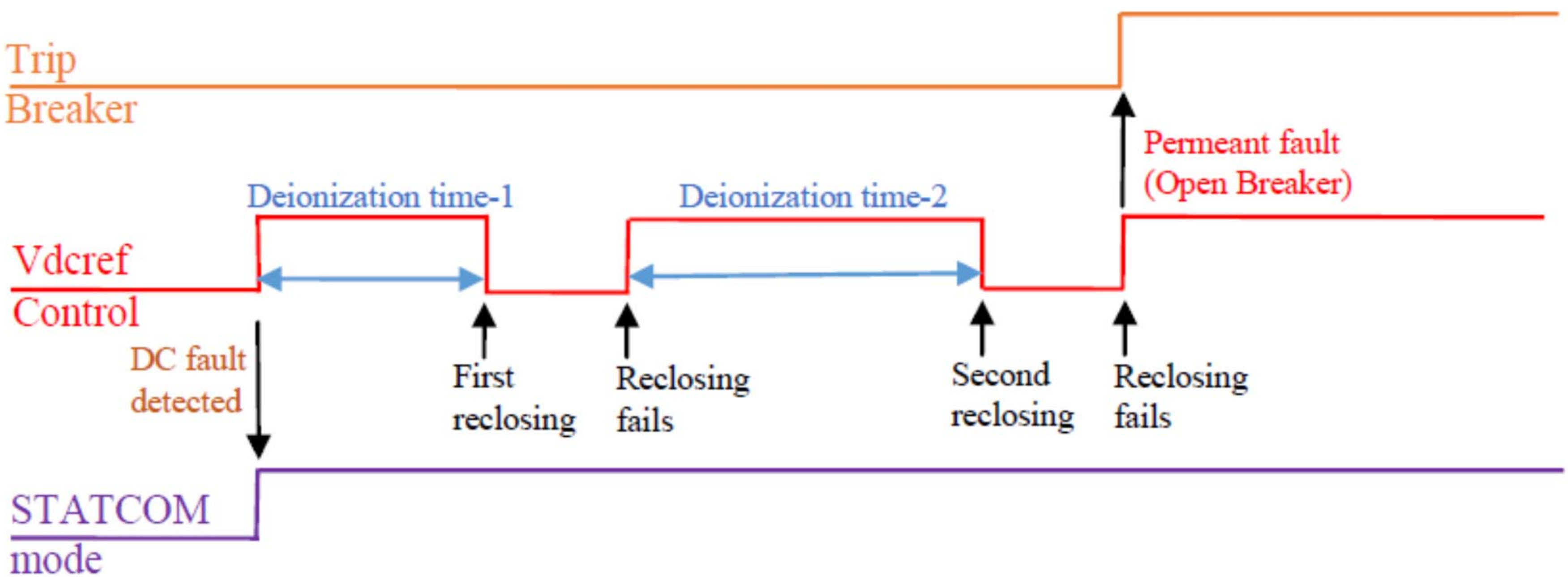
- Will cause sudden discharge of cable
- Will cause overvoltage on the healthy conductor
- Will be detected and cause blocking of all sub-modules; a trip signal is issued at the same time
- After blocking the pole-pole dc is determined by diodes only (limited to peak phase-phase voltage)
- Normally cleared by opening ac breakers at both ends, can restart after discharging the cable

Fault Performance

Pole-to-pole fault in symmetrical monopole with HB

- Will discharge both converter capacitors and cables
- Will be fed from all AC systems through diodes
- Will appear like a high impedance fault to all AC systems
- All IGBT's are blocked
- Will cause protective thyristors to be triggered at all sub-modules; trip signal will be issued to all ac breakers

- A pole to ground fault in bipolar or asymmetrical monopole will have the same behavior

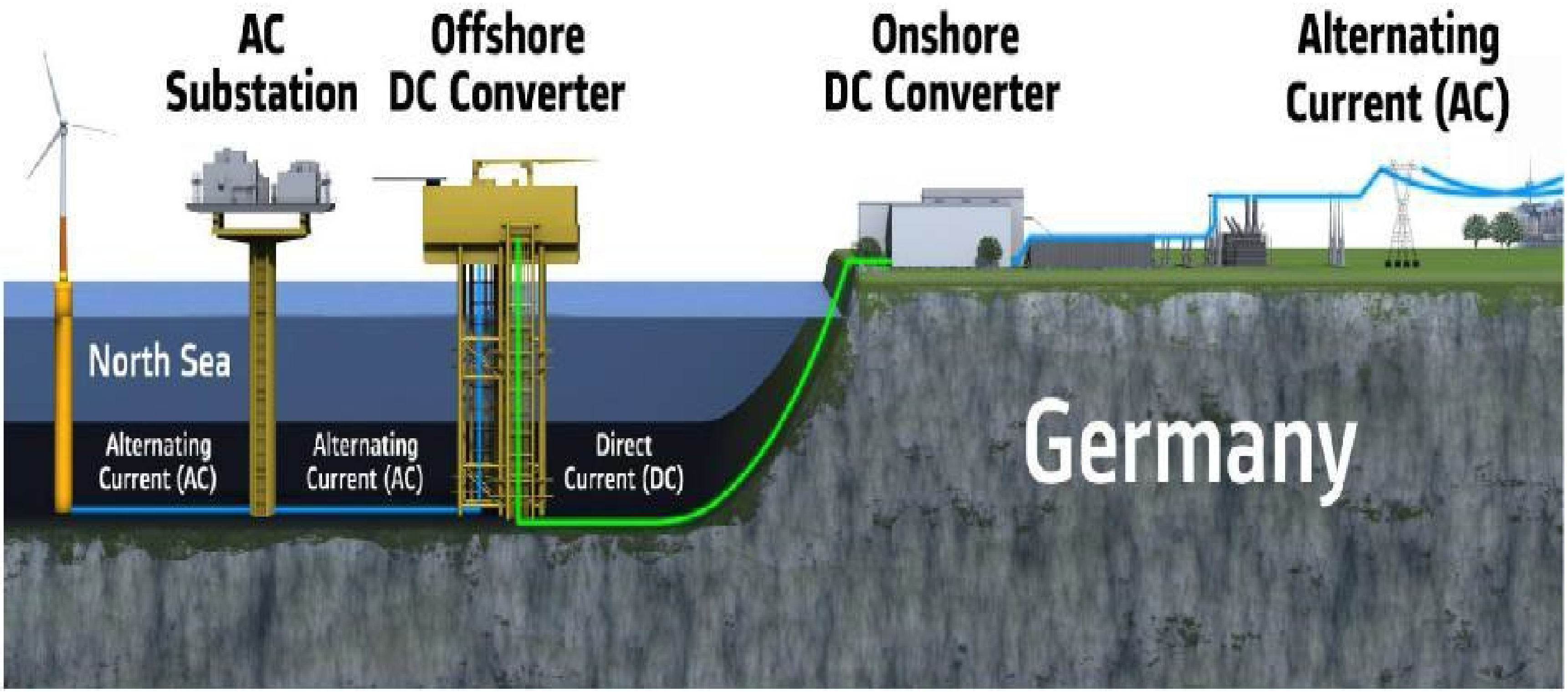


Fault clearing using a full bridge
Cigre Symposium 2015 Lund Sweden paper 113

Offshore wind power integration

In a typical offshore wind integration project, the location is typically between 150-200 km from the point of common coupling (PCC), including both offshore and on shore cables to the converter terminal, thereby making HVDC the most appropriate technology to use for power transmission to mainland grids, recognizing the limitations in AC submarine transmission at such distances. In addition, VSC HVDC technology offers several unique advantages suitable for such environmentally harsh and difficult conditions, with yet greater energy yield potentials.

HVDC


AC
Substation
Offshore
DC Converter
Onshore
DC Converter
Alternating
Current (AC)
North Sea
Alternating
Current (AC)
Alternating
Current (AC)
Direct
Current (DC)
Germany

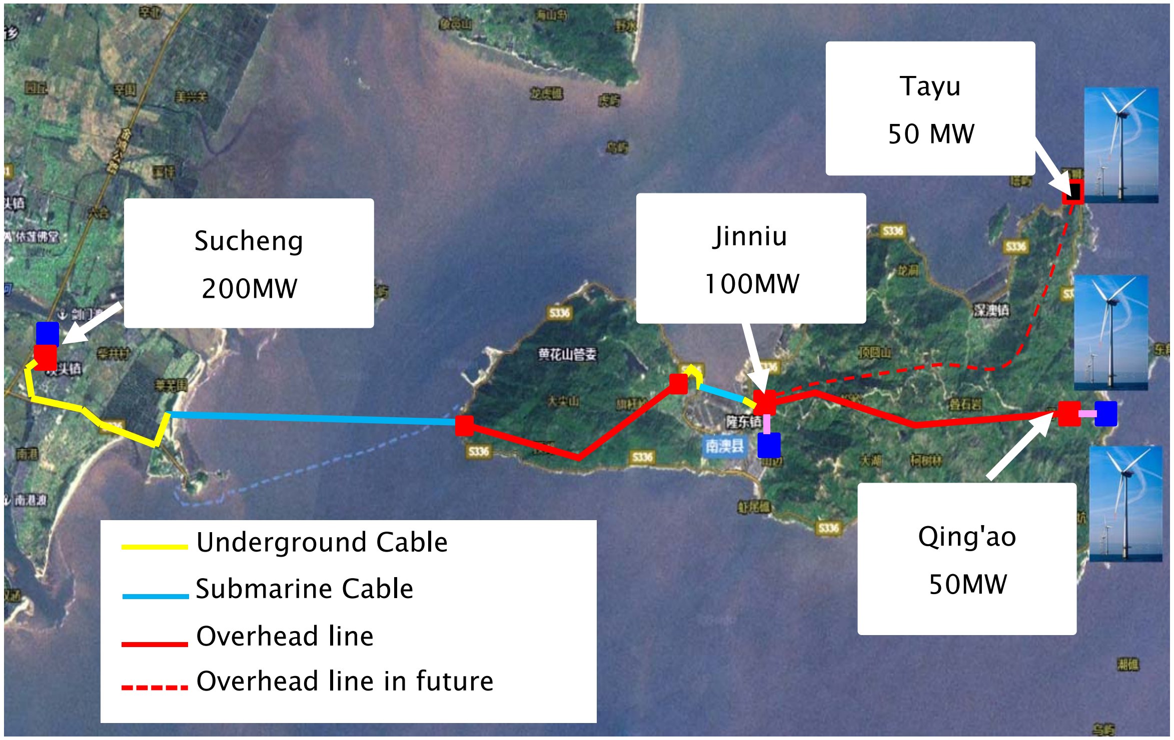
Off-Shore VSC requirements

As compared to a completely onshore VSC HVDC link, the VSC HVDC link which connects an

offshore WPP to the onshore AC system may have special requirements. For example:

- A braking chopper in the onshore converter station
- Multiple/parallel transformers in both converter stations. Each transformer is typically rated to transmit more than 50% of the WPP power (sometimes up to 100% in case of another transformer outage), and requires a more sophisticated mechanical design to withstand particularly the harsh offshore environmental conditions. It must be noted that selection of the transformer also requires cost-benefit analysis
- Other main considerations include outage time and reliability. For example, accessibility of the offshore VSC HVDC platform and maintenance

Renewable energy Integration



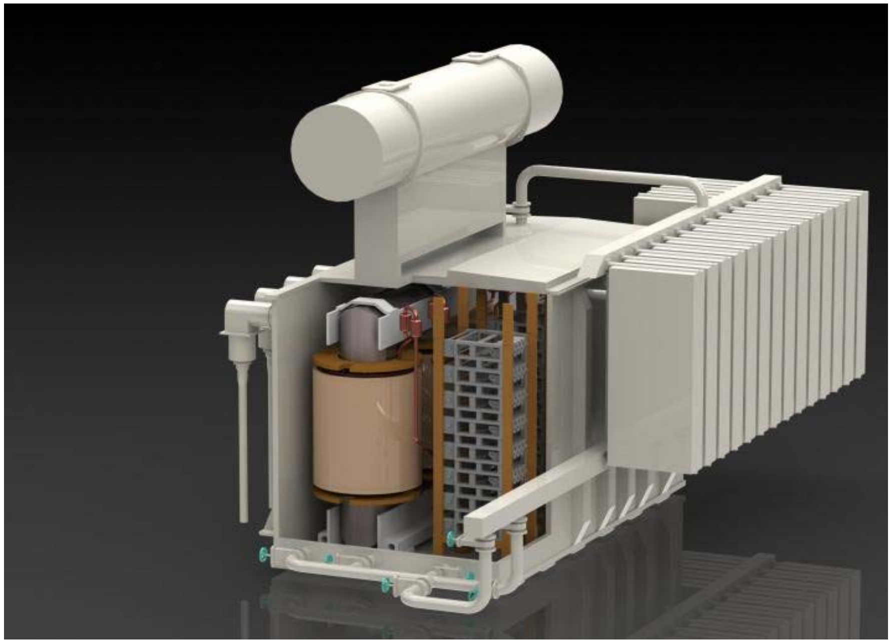
VSC Project – Renewable Energy Integration
Nan'ao ±160 kV VSC-MTDC Project

- The first multi-terminal VSC-HVDC project
- Wind Energy of Nan'ao island is transported to mainland power grid by AC and DC lines in parallel
- Commissioned in 2013

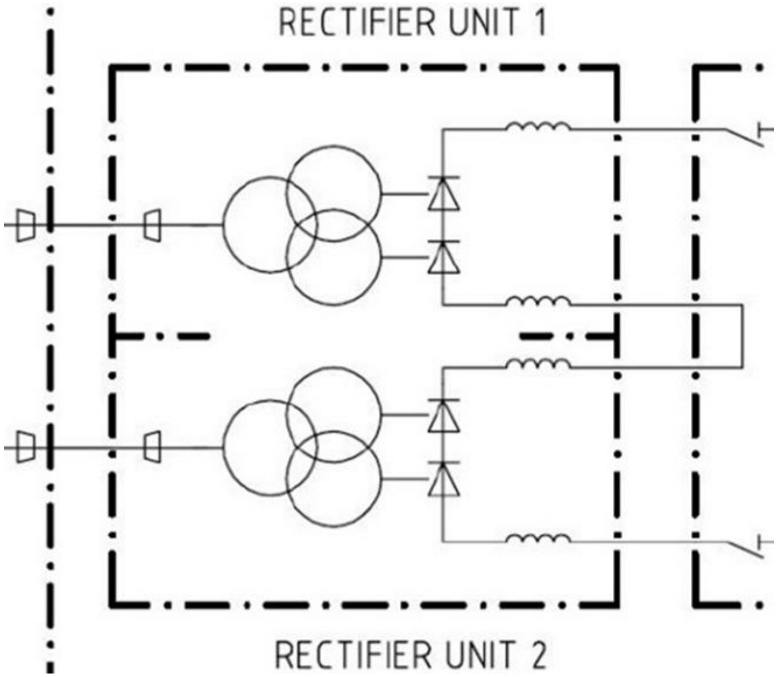
±160 kV, 200/100/50/50MW
Overhead Line (20.6km in total),
Underground Cable (9.5 km),
Submarine Cable 10.7 km

Curtesy to SERPI of CSG

HVDC Future

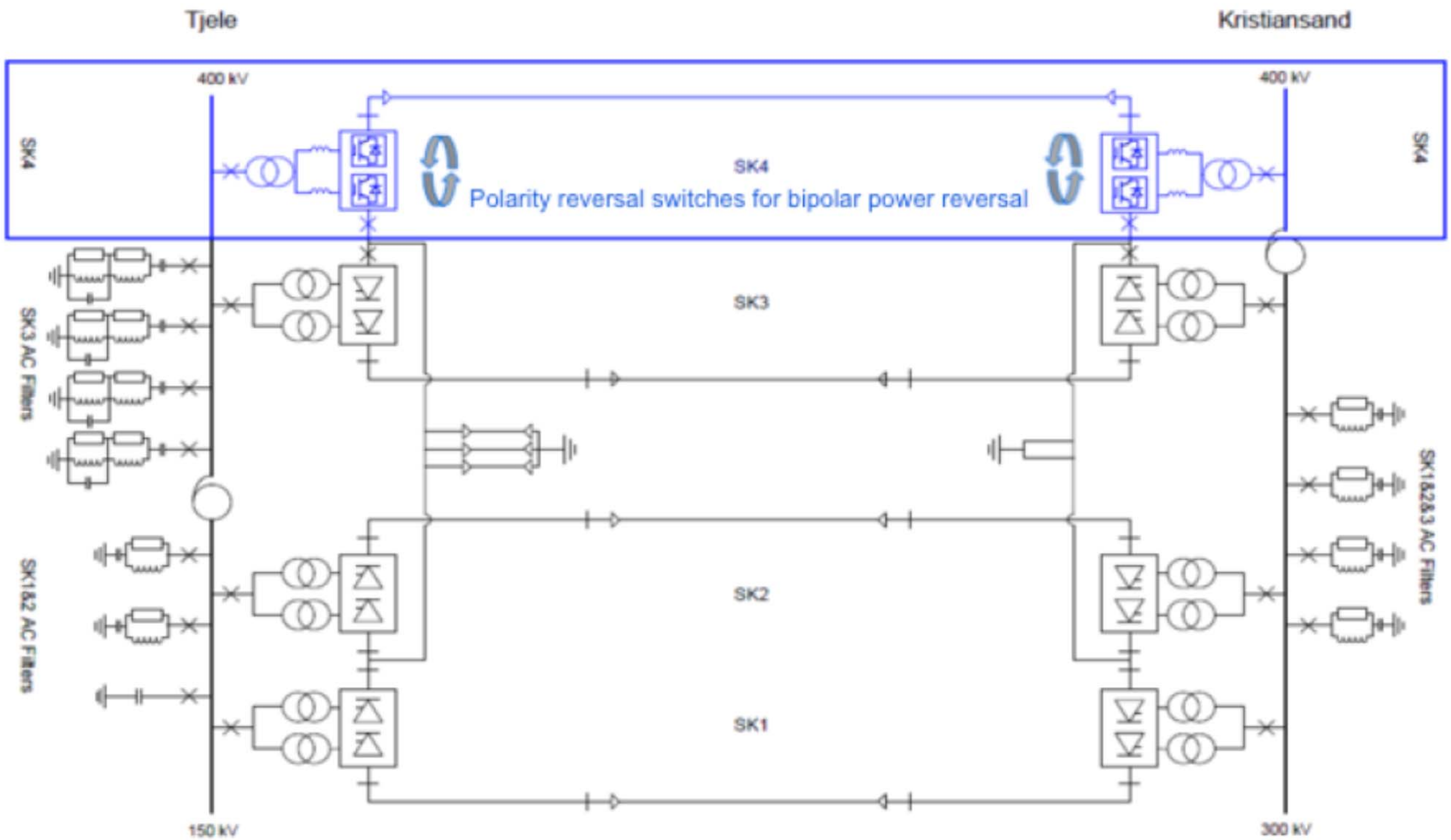


HVDC Diode rectifier unit complete with transformer smoothing reactor cooling



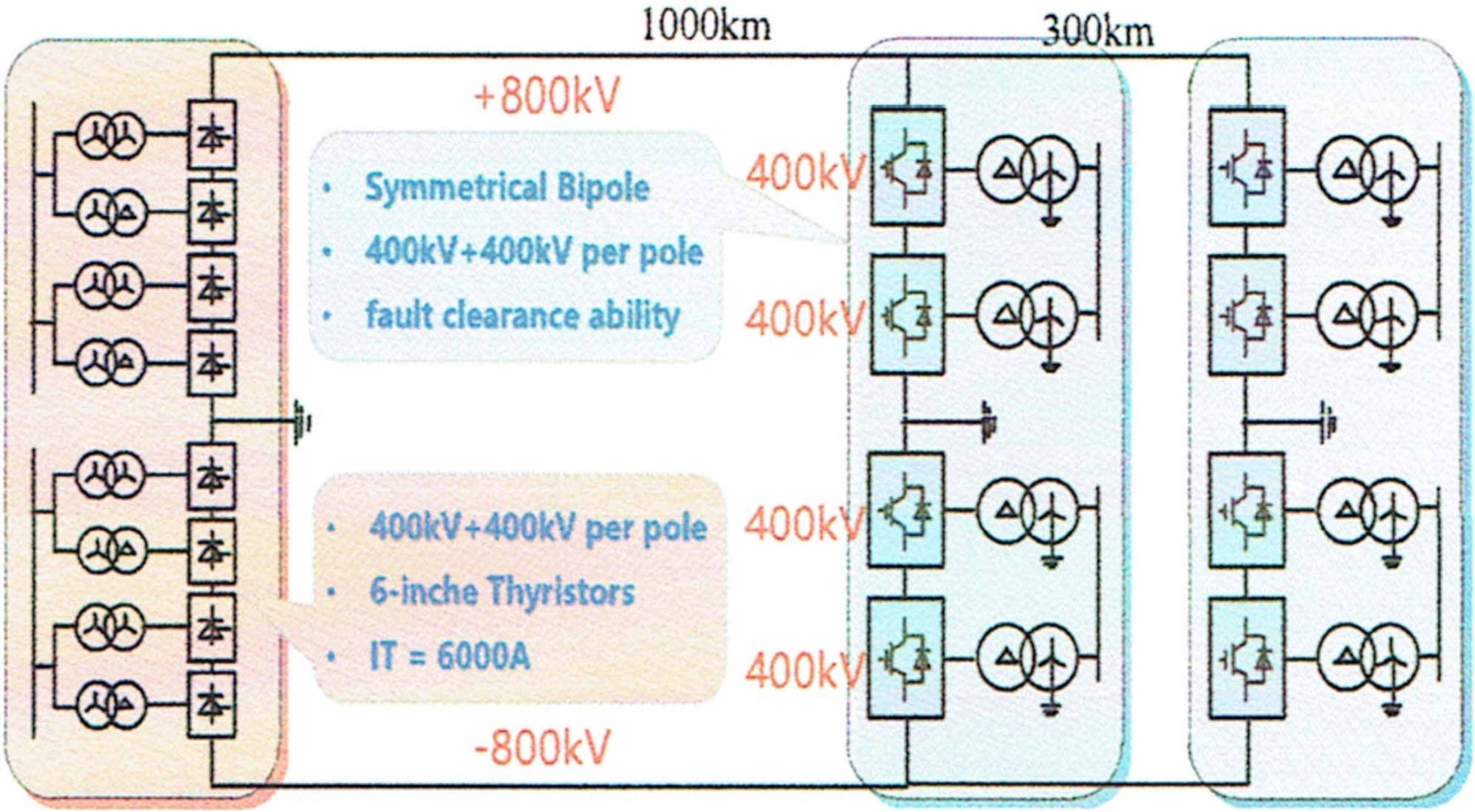
Connection of HVDC diode rectifier units

The cooling and insulation is utilizing synthetic based ester liquids- The last time oil immersed valves were used was almost 50 years ago in Cahora Bassa HVDC system between SA and Mozambique. One end is still oil immersed outdoor valves

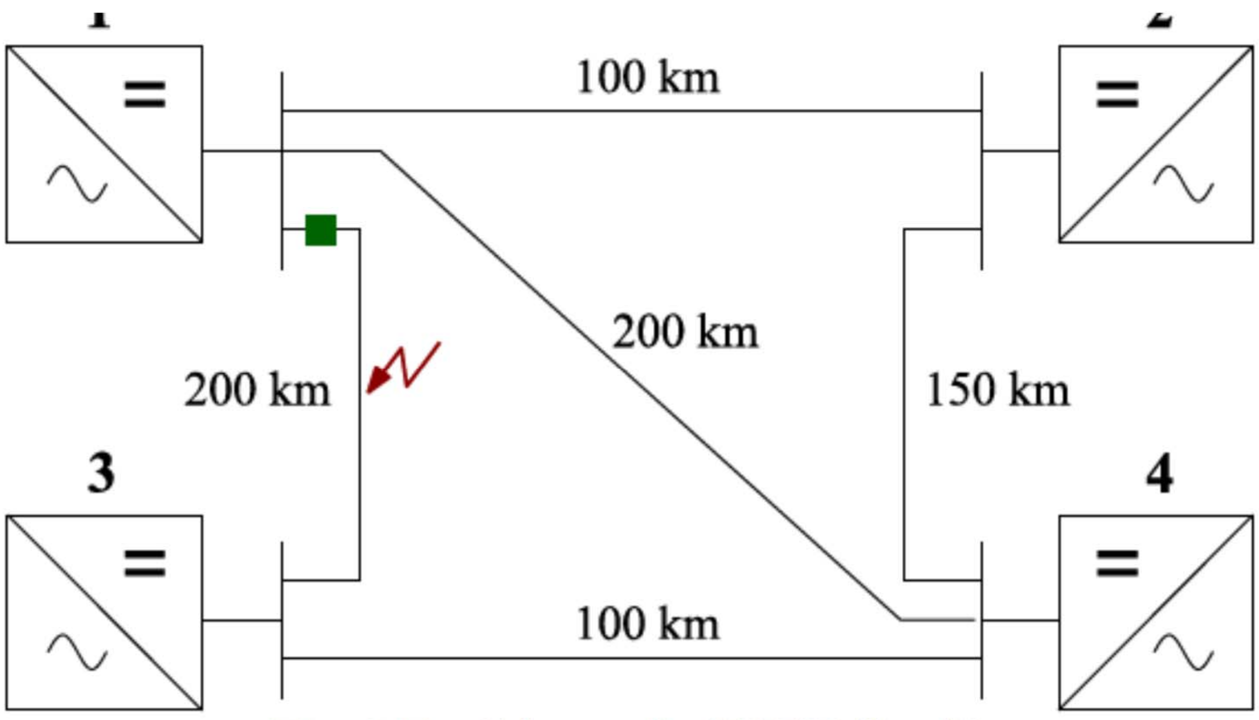


Cigre Lund Symposium

HVDC Future


1000km
300km
+800kV
Symmetrical Bipole
400kV+400kV per pole
fault clearance ability
400kV
400kV
400kV
400kV
400kV+400kV per pole
6-inche Thyristors
IT = 6000A
-800kV

DC Grids



Aspects of DC Grids

- ❑ Control strategy
- ❑ Protection
- ❑ Reliability
- ❑ Grid code
- ❑ Breakers
- ❑ DC-DC converters

HVDC and FACTS performance

- Protocol for reporting of performance of HVDC systems Cigre TB 590
- Protocol for reporting operational performance of FACTS TB 717

HVDC PERFORMANCE

Cigre HVDC Performance Report Started in 1968

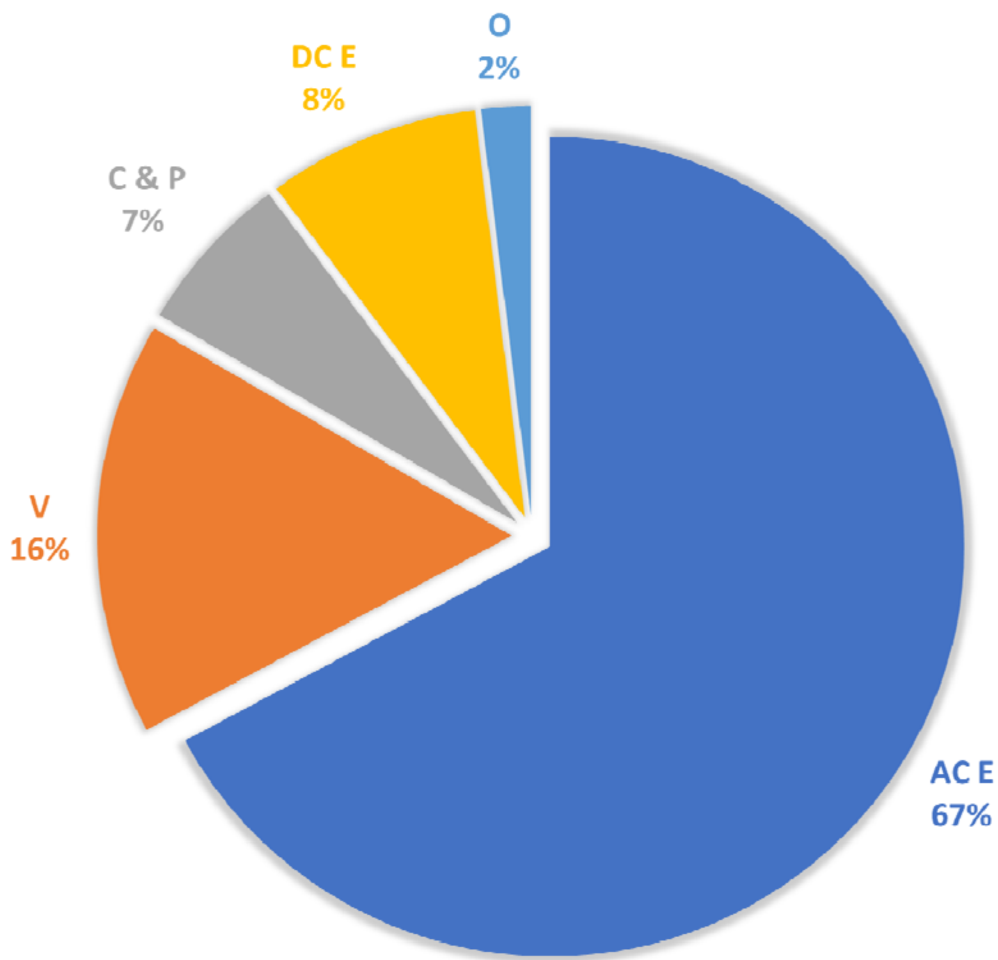
Protocol for Reporting the Operational Performance of HVDC (Latest revision TB 590)

55 HVDC Systems have reported

Factors affecting HVDC Performance

- Equipment Rating/performance
- System faults
- Redundancy
- Spares
- Operator skills

BREAKDOWN OF FEU BY EQUIPMENT CATEGORY OF ALL REPORTING (1979-2016)



AC-E: all ac main circuit equipment including ac filters and other reactive power equipment, ac control & protection, converter transformer and synchronous compensator, auxiliary equipment & auxiliary power and other ac switchyard equipment.

Valve: all parts of the valves including electrical, cooling, capacitors and phase reactor as well as all auxiliaries and components integral with the valve and forming part of the operative array.

C&P: dc control and protection equipment used for control of the overall HVDC system and for the control, monitoring and protection of each HVDC substation

DC-E: all equipment at the HVDC substations except for that in the three categories AC-E, Valves and C&P. This category includes the DC smoothing reactors, DC switching equipment, DC measurement equipment, ground electrodes and electrode lines, and other DC Switchyard and Valve Hall Equipment.

Other: Human error or unknown causes

Thank you Cigre SC B4