Applications of VSC Converters in HVDC

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TransGrid Solutions

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1. VSC developments
2. Semi-conductor devices
3. Technology options
4. Configurations
5. Applications
6. Fault behaviour
7. Conclusions

HVDC Technology selection

Application	LCC	VSC	Comment
Back-to-Back	Yes	Yes	
Long Distance Transmission	Yes	Yes	
Connecting Isolated systems	Yes	Yes	VSC has advantage for weak isolated systems
Connecting Offshore Wind	Less Suitable	Yes	
Frequency Changer	Yes	Yes	
Overhead Lines	Yes	Yes	VSC requires FB, HyB, DC Breaker for fast fault clearing
Cable systems	Yes (MI, MIPPL, OF)	Yes (as LCC+ Extruded)	MI
Multi-terminal Operation	Yes	Yes	More difficult with LCC
Very High Power (above 3000 MW)	Yes	No	VSC is under development
System Recovery Services	No	Yes	Black Start

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VSC developments

VSC Developments and Milestones

- 1997 the first introduction of the Voltage Source Converter VSC technology in an experimental project. The Hellsjön project at 10 kV and 3 MW.
- Few projects were constructed. Examples are Murray Link 200 MW and Cross Sound Cable 330 MW in 2002. Two and three level converters utilizing pulse width modulation were utilized. High converter losses and having only one manufacturer led to the slow increase in the number of projects
- The introduction in 2006 of the multi module converter (MMC) in the Trans Bay Cable project led to the fast increase in the applications of the VSC converters. The MMC converter is characterized by low losses. Having more than one manufacturer was very important for the industry

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Sample VSC projects

Project	Location	Type of transmission	DC voltage KV	DC power MW	Converter	In service date	Configuration
Trans Bay Cable	USA	Submarine cable 80 km	+/- 200	400	Half bridge	2006	Symmetrical monopole
INELFE	Spain to France	Land Cables 60 km	+/-320	2X1000	Half bridge	2015	Symmetrical monopole
BorWin 3	Germany Offshore	Land cable 33 km Submarine cable 130 km	+/- 320	900	Half bridge	2019	Symmetrical monopole
NEMO	UK-Belgium	Land cable 10 km Submarine 130 km	+/- 400	1000	Half bridge	2019	Symmetrical monopole
Cobra Cable	Denmark-Netherlands	Submarine cable 325 km	+/- 320	700	Half bridge	2019	Symmetrical monopole
Ultranet	Germany	Overhead line AC line converted to DC	+/- 380	2000	Full bridge	2022	Bipole
Allegro	Belgium - Germany	Land Cable 90 km	+/- 320	1000	Half bridge	2020	Symmetrical monopole
Maritime link	Canada Nova Scotia to Newfoundland	Overhead line 187 km Submarine cable 170 km	+/-200	500	Cascaded converter (half bridge)	2017	Bipole
Nordlink	Norway-Germany	Submarine cable 200 km	+/- 525	1400	Half bridge	2020	Symmetrical monopole
North Sea Network NSN	Norway-UK	Submarine cable 730 km	+/-525	1400	Half bridge	2021	Symmetrical monopole
Viking Cable	UK-Denmark	Submarine cable 760 km	+/-525	2X700		Tendering stage (2022/2023)	Rigid bipole
Skagerrak 4	Norway-Denmark	Land Cable 102 km Submarine cable 137 km	500	700	Cascaded converter (half bridge)	2014	Hybrid bipole with Skaggerak 3

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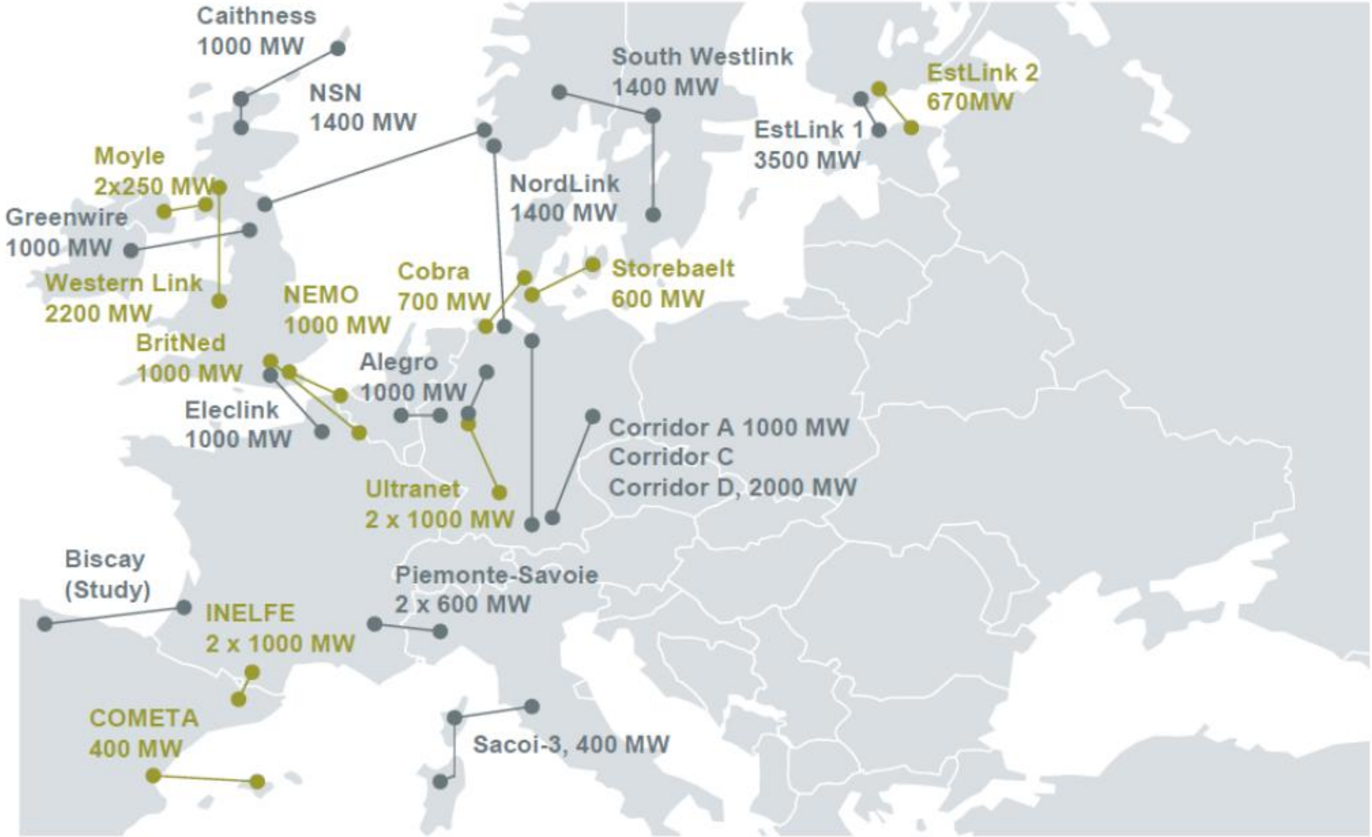
European DC projects



VSC projects

- It is clear the majority of the VSC applications are cable projects. There are reasons for such choice:

1. Cost effectiveness of XLPE cables suitable for the VSC applications
2. Many interconnections between countries through bodies of water
3. The technical issues for clearing dc overhead line faults with the VSC converters
4. Offshore wind integration
5. Environmental concerns over the construction of new overhead lines

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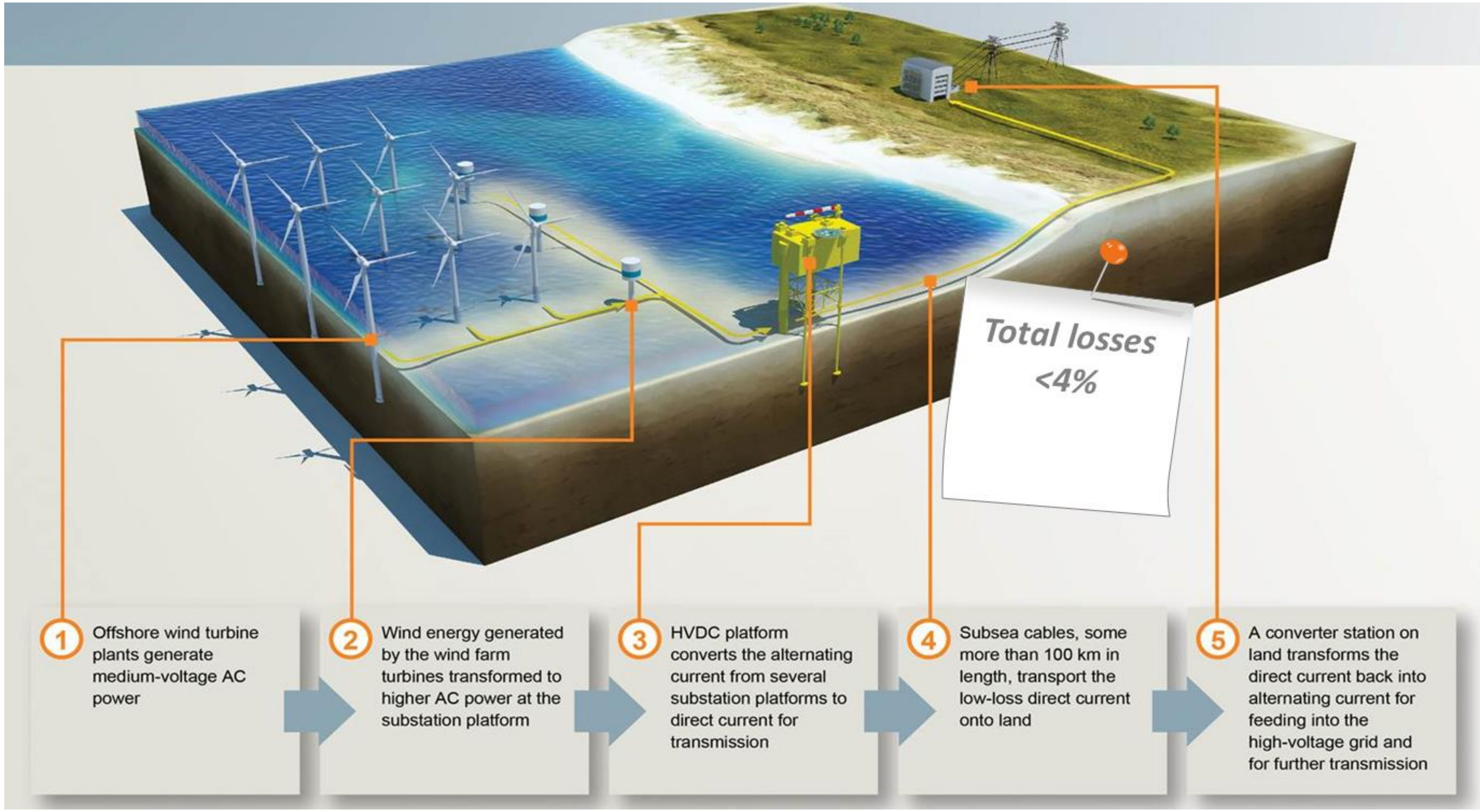
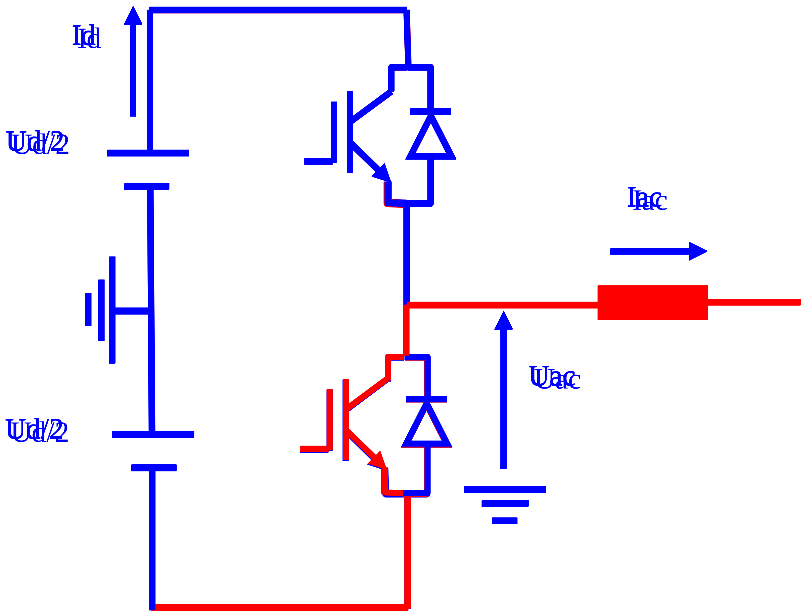
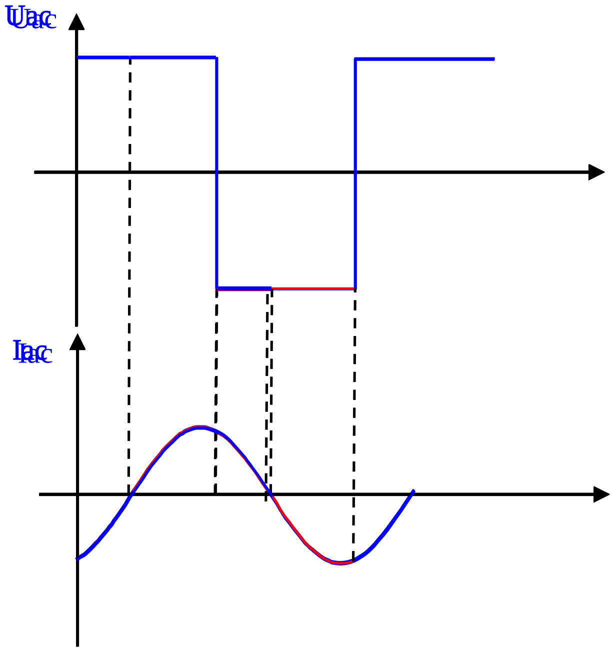
Off-Shore Wind integration



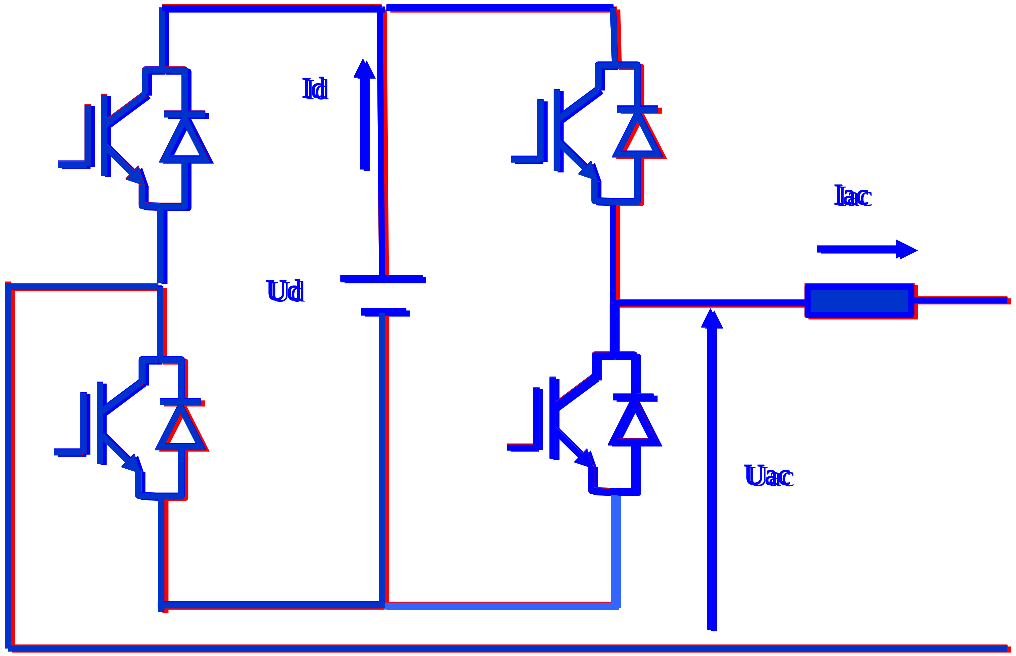
VSC Half Bridge

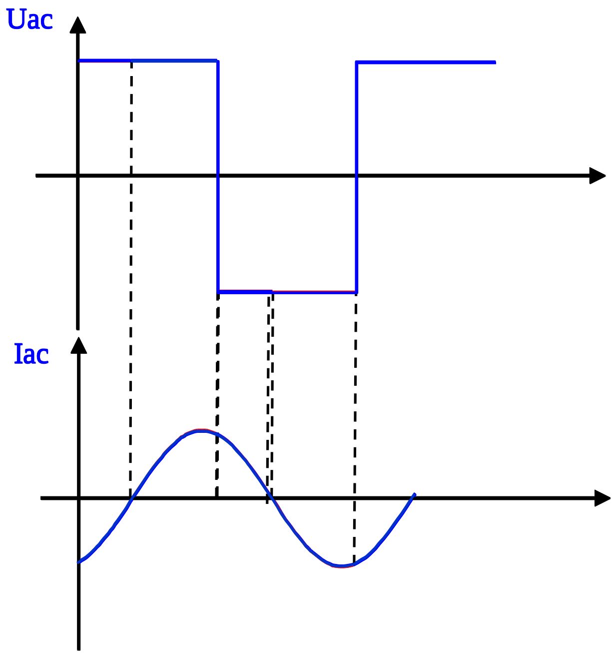




- Current path during the four quadrants

VSC Full Bridge

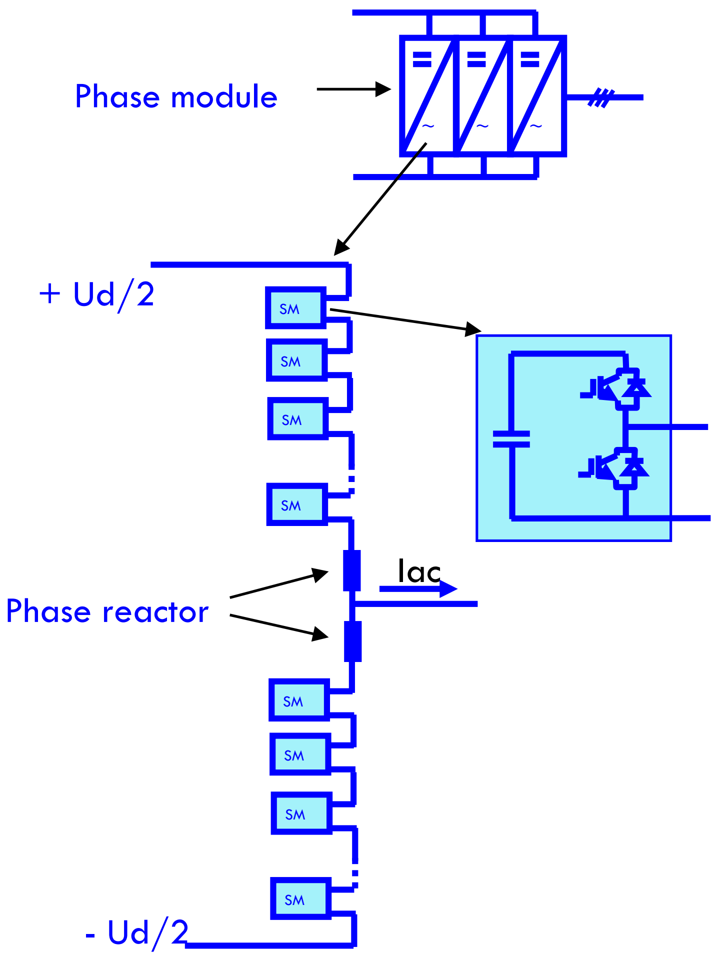




- Current path during the four quadrants

Multi-Module VSC

Operation Principles



- Each arm contains N submodules
- SM Capacitor voltages are kept almost equal, Uc≈Ud/N
- Each SM can be either OFF or bypassed (lower IGBT triggered, zero voltage at terminals) or ON (upper IGBT triggered, capacitor voltage at terminals)

Multi-Module VSC

Half-bridge vs. Full-bridge VSC Converter
Best solution depends on transmission requirements

Half-Bridge

Lower CAPEX	✓
Less components	✓
Lower losses	✓
Proven technology since beginning of VSC technology	✓
Applicable when the 1.5s to 3s DC line fault recovery time is acceptable	
In case of fault the AC circuit breaker must be opened	
DC voltage must be higher than AC ph. to ph. peak voltage	

Full-Bridge

Higher CAPEX	
More components	
Higher losses	
Applicable when the DC fault recovery time must be as fast as with LCC, e.g. 160 ms.	✓
In case of fault there is no need to open AC circuit breaker, reactive power can continued	✓
DC voltage control is independent from AC voltage. Reduced DC voltage operation.	✓
Converter AC terminal faults can be controlled in bipolar configuration with low impedance grounding of the DC circuit	✓

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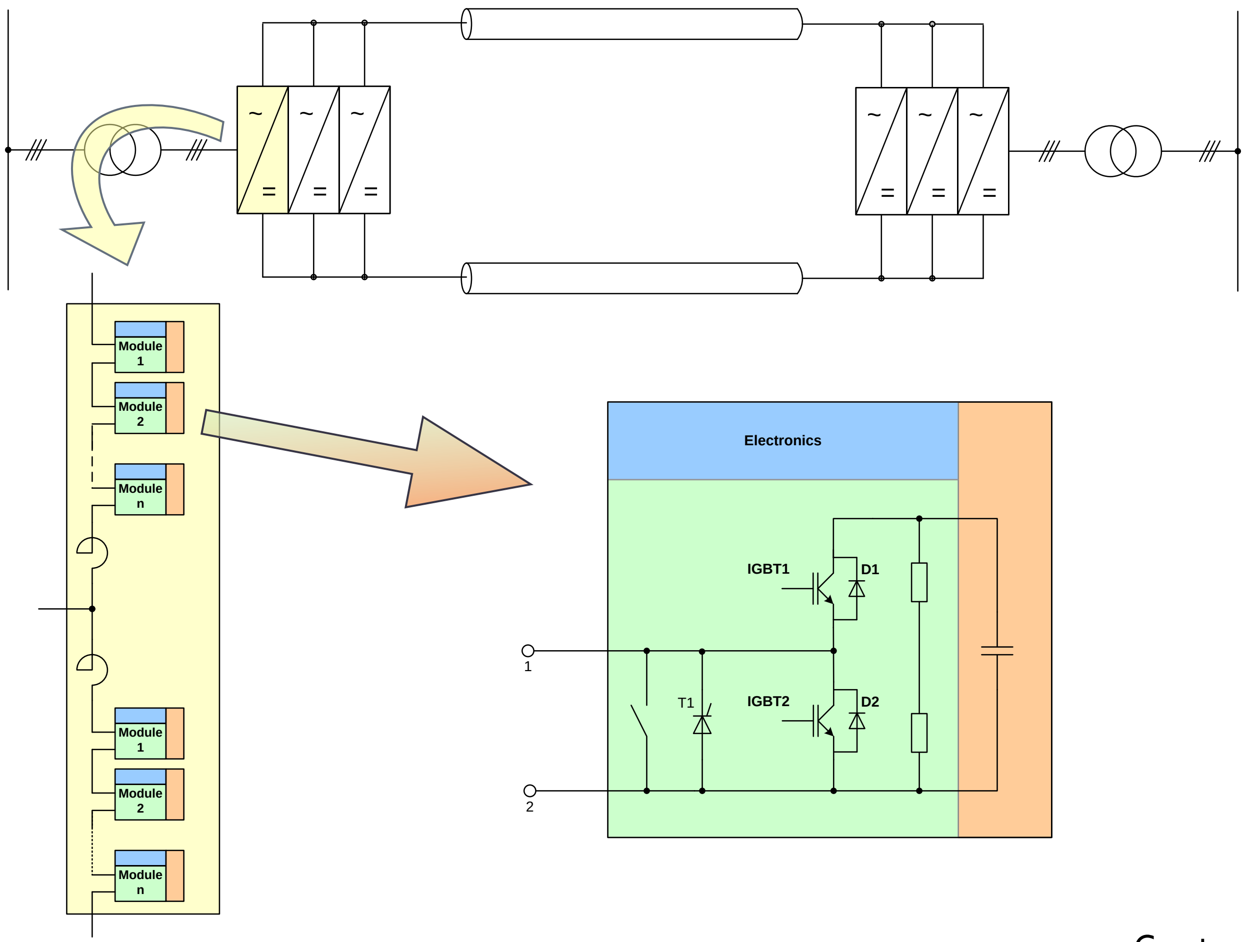
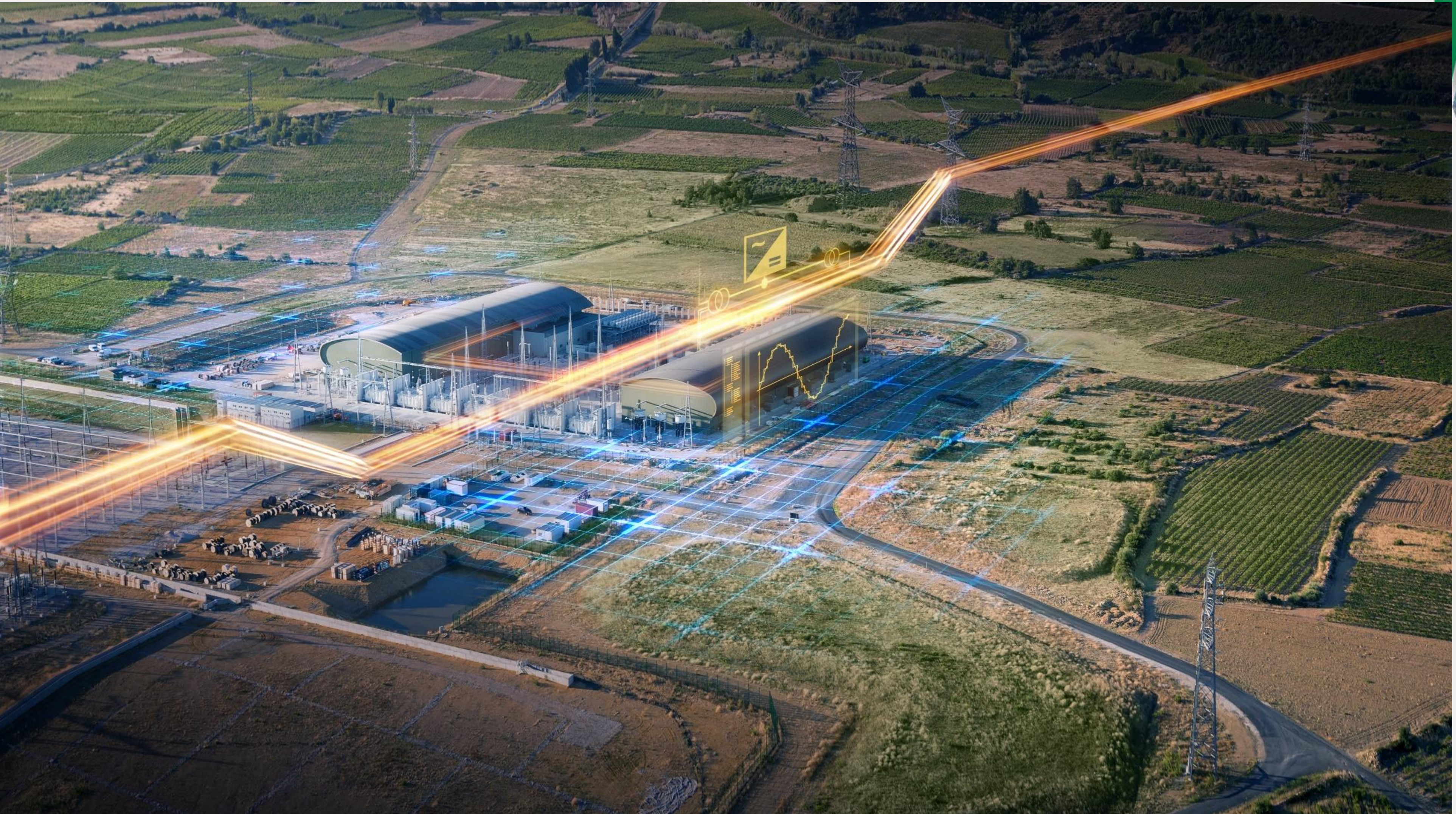
Converter Station Equipment– Phase Module



Courtesy of Siemens

Converter Hall



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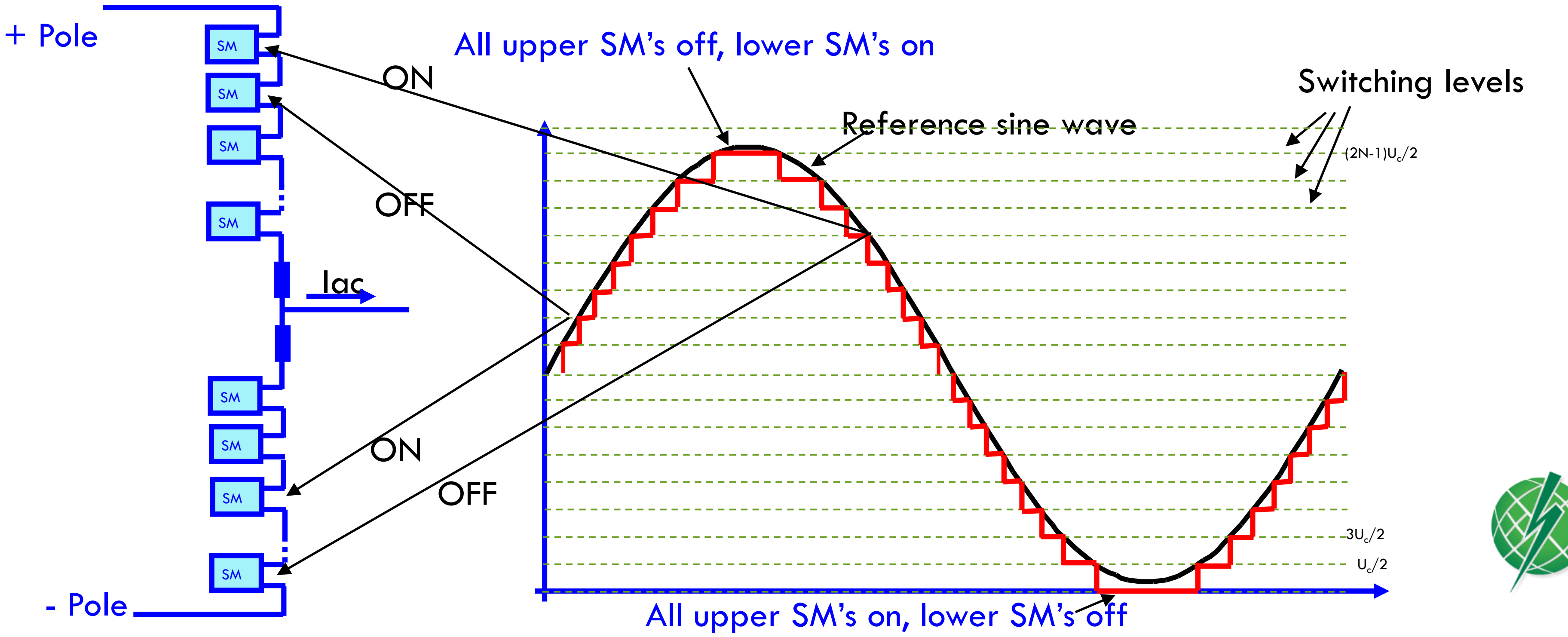
Multi-Module VSC

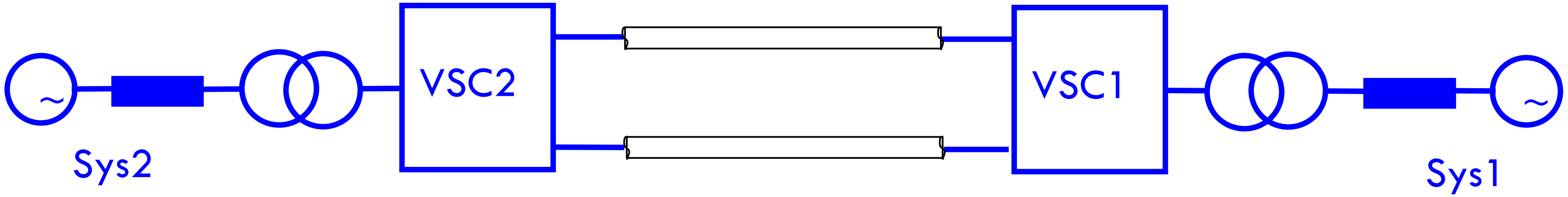
Modulation Techniques

- Nearest Level Control:
  - ✓ **reference voltage is compared with fixed levels, every time it crosses a level a sub-module is turned on or off**



VSC Application

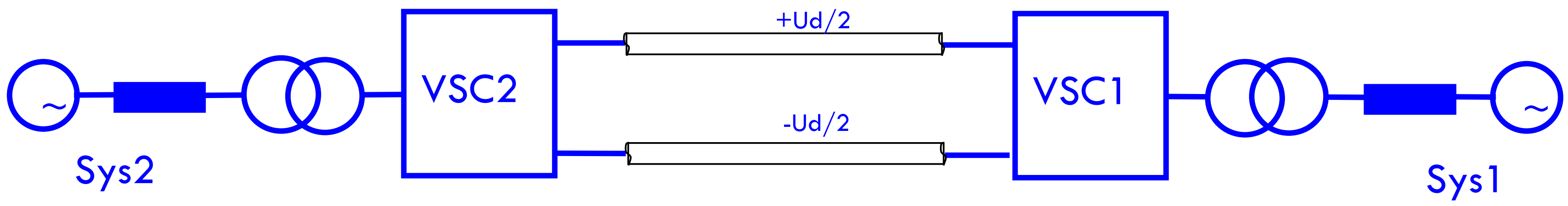
HVDC Transmission



- 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

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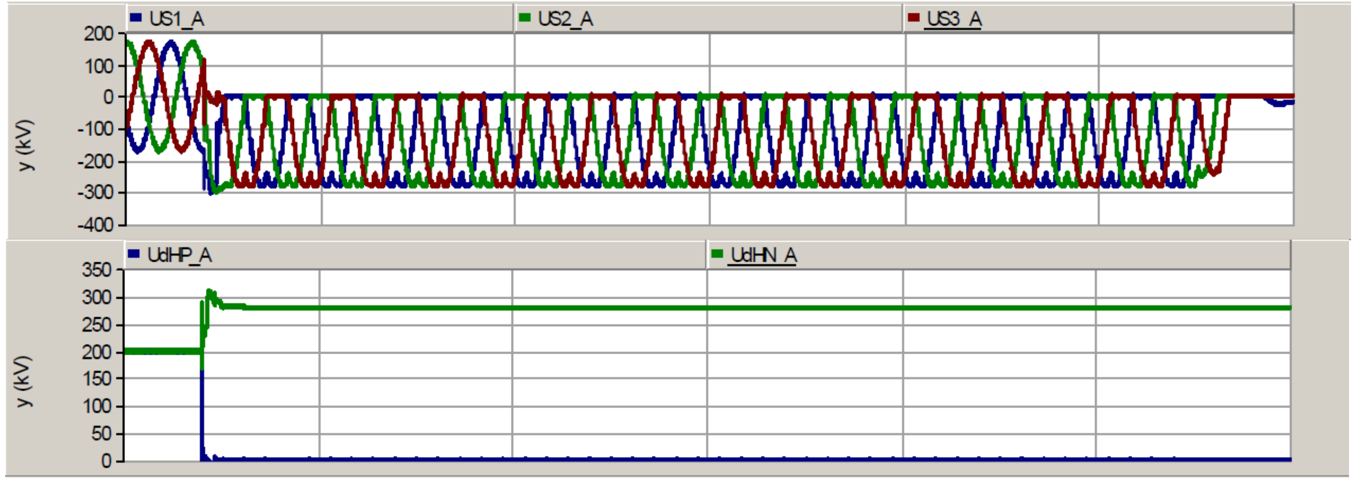
Fault Performance

- Pole to ground fault
  - ✓ **Will cause sudden discharge of cable**
  - ✓ **Will cause overvoltage on the healthy pole**
  - ✓ **Will be detected and cause blocking of all sub-modules (in 20us); 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)**

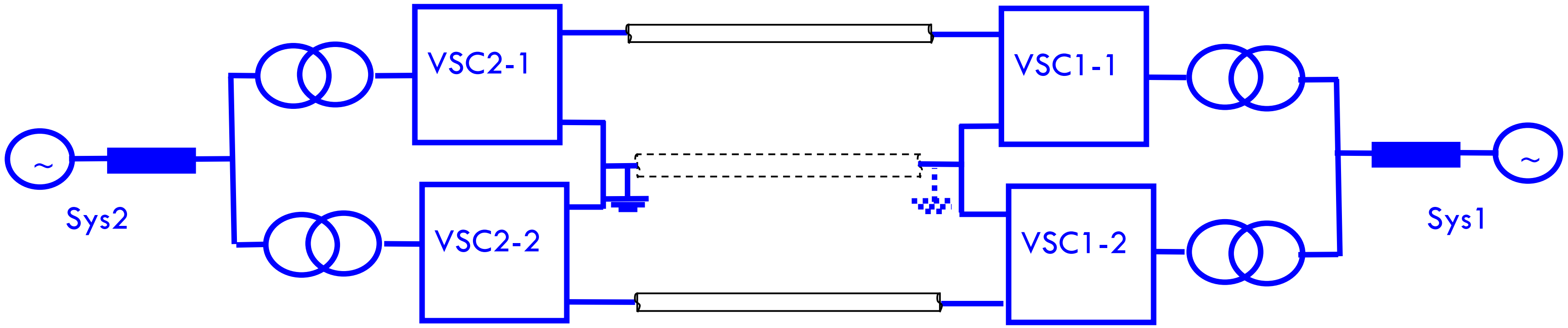


Secondary side AC voltages

DC voltages

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

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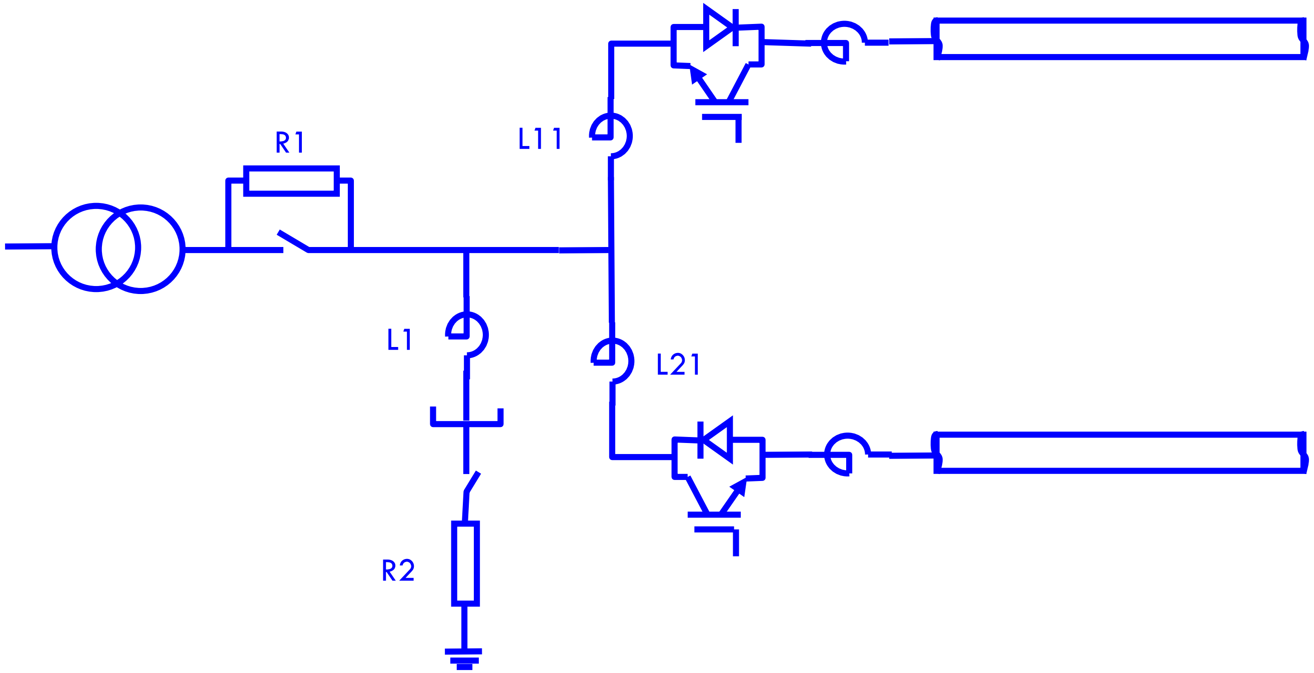
Converter Station Equipment



VSC - HVDC Transmission

Impact of long cables

- Long dc cables means large dc circuit capacitance
- It means longer time to charge the cable during start up
- Higher discharge currents during station/converter faults
- Rate of change of current has to be taken into consideration during faults
- Locating cable fault locations
- Resonance because of the large capacitance
- Discharging the cable following switch off and opening the ac breakers

Thank You SC B4
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