TSFS11 HVDC

Lecture 13

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ISY/EKS

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Outline

- HVDC Introduction
- Classic HVDC Basic principles
- VSC HVDC Basic principles
- VSC in the power grid - Wind applications

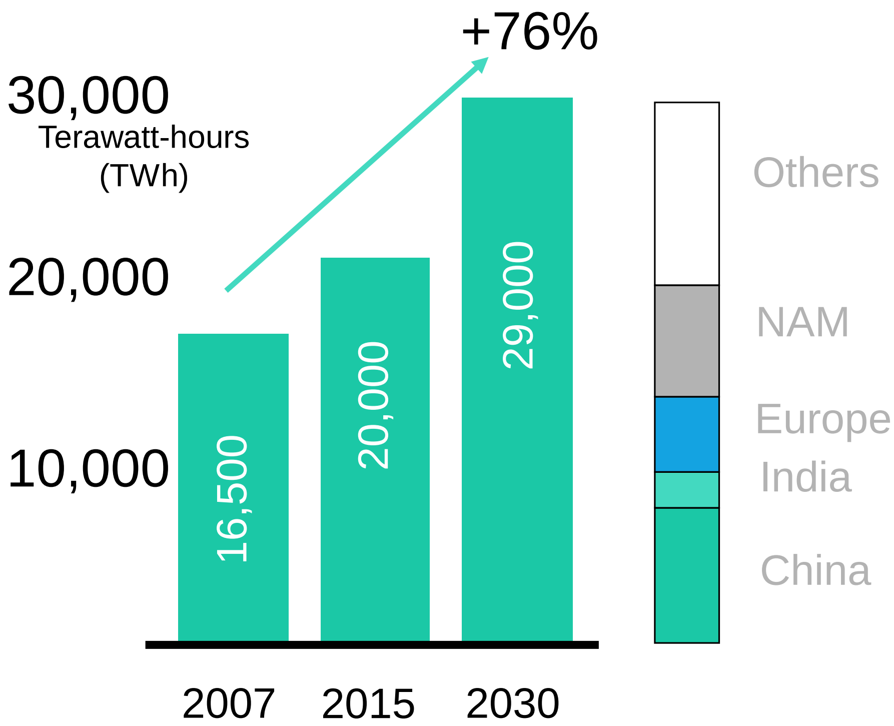
HVDC Introduction

High
Voltage
Direct
Current

Tackling society’s challenges on path to low-carbon era means helping utilities do more using less

Forecast rise in electricity consumption by 2030

▪Source: IEA, World Energy Outlook 2009



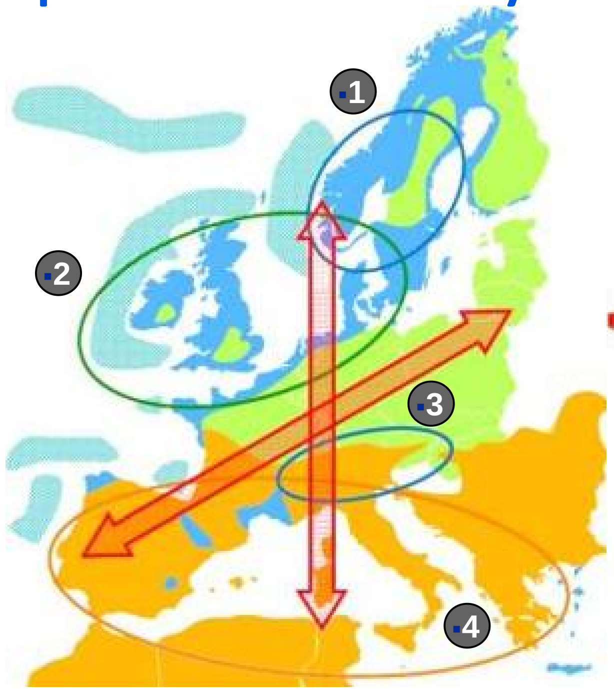
Solutions are needed for:

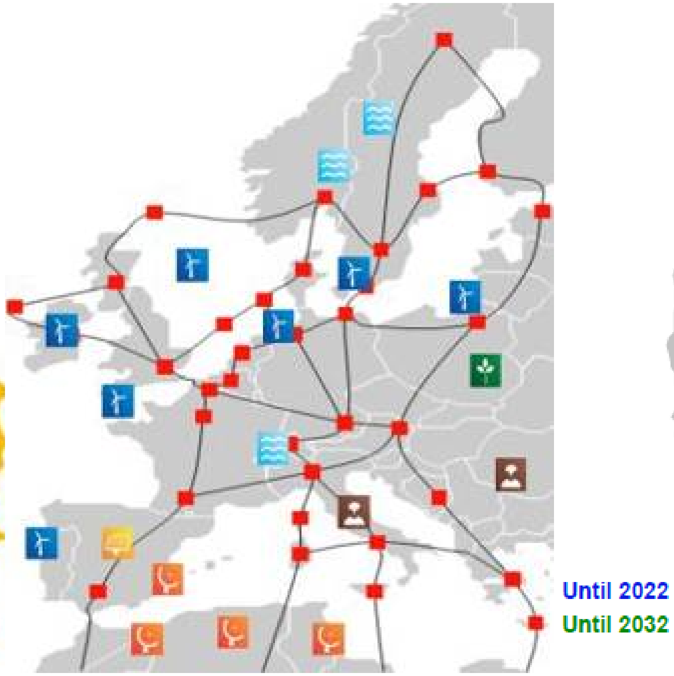
- Rising demand for electricity – more generation
- Increasing energy efficiency - improving capacity of existing network
- Reducing CO_2 emissions – Introduce high level of renewable integration

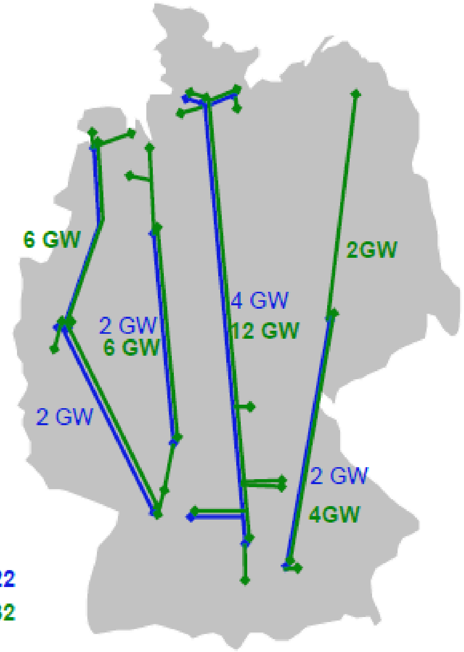
Meeting the rise in demand will mean adding a 1 GW power plant and all related infrastructure every week for the next 20 years

The evolution of grids: Connect remote renewables

Europe & Germany are planning large scale VSC-HVDC







Source: DG Energy, European Commission

European Visions

1. Hydro power & pump storage -Scandinavia
2. >50 GW wind power in North Sea and Baltic Sea
3. Hydro power & pump storage plants - Alps
4. Solar power in S.Europe, N.Africa & Middle East

Germany (draft grid master plan)

- Alternatives to nuclear-distributed generation
- Role of offshore wind / other renewables
- Political commitment
- Investment demand and conditions
- Need to strengthen existing grid

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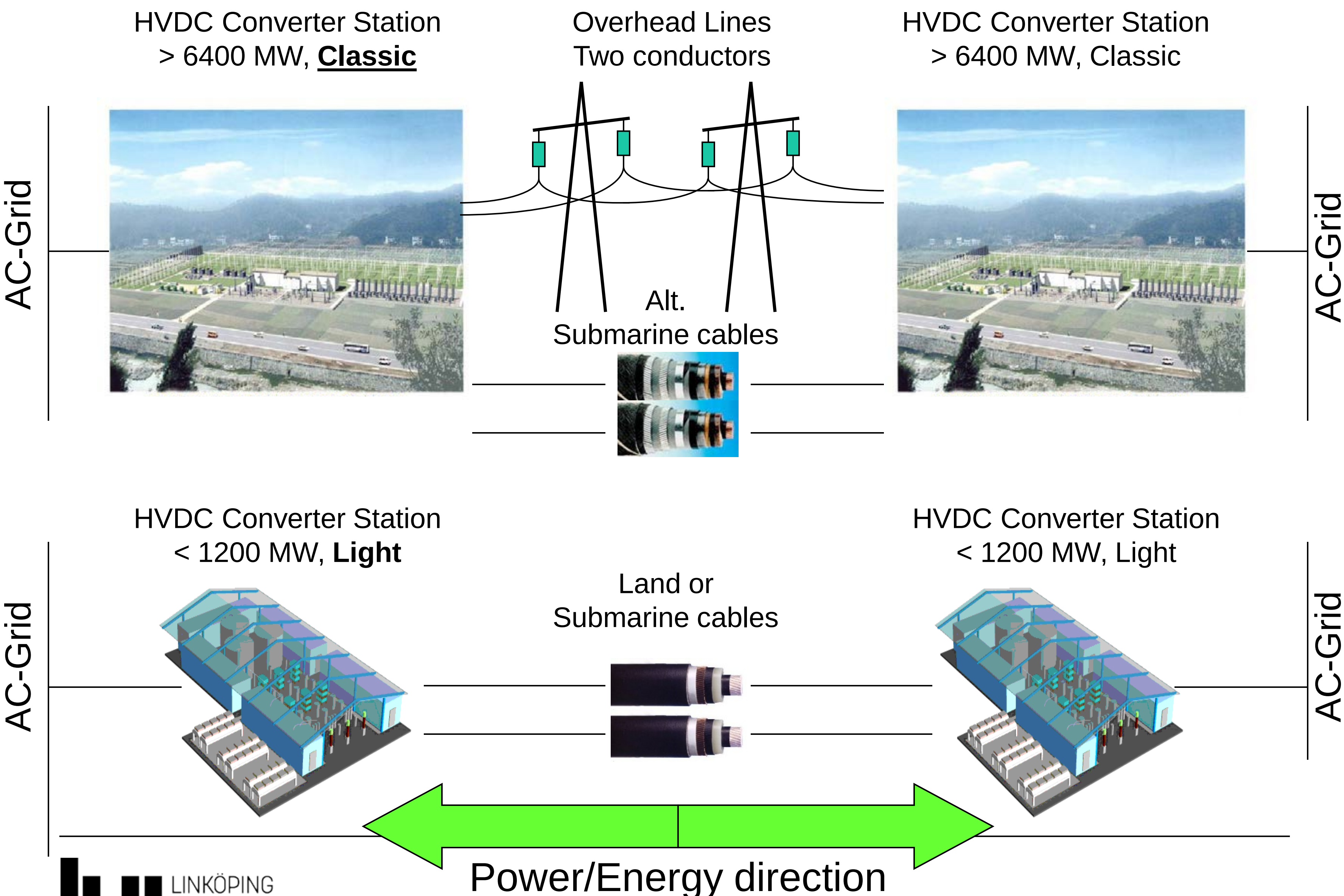
What is an HVDC Transmission System?



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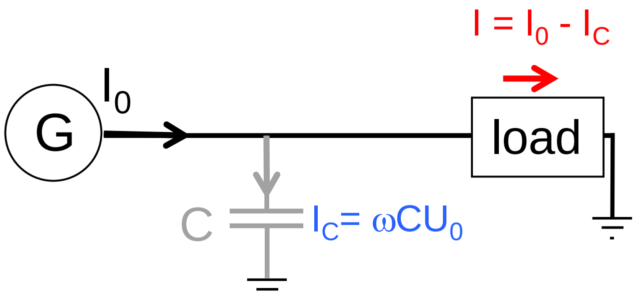
Why HVDC is ideal for long distance transmission?

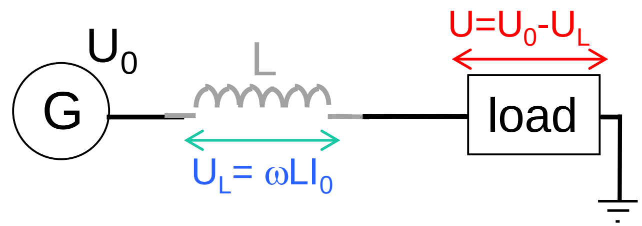
Capacitance and Inductance of the power line

Cable



In cable > 50 km, most of AC current is needed to charge and discharge the “C“ (capacitance) of the cable

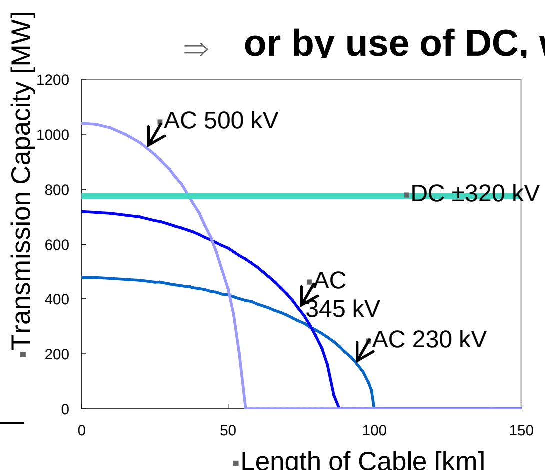
Overhead Line

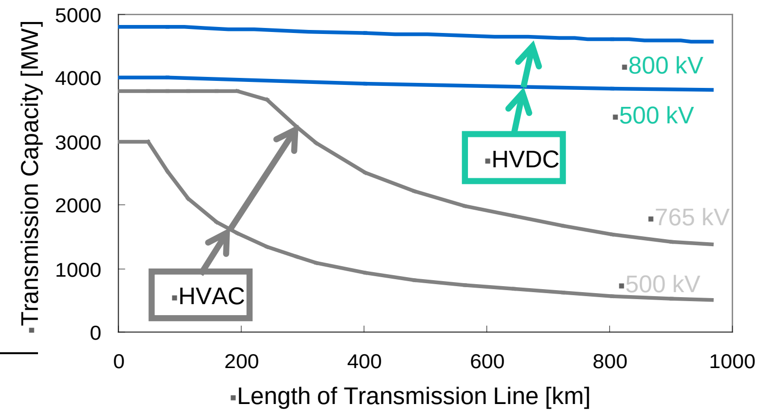


In overhead lines > 200 km, most of AC voltage is needed to overcome the “L” (inductance) of the line

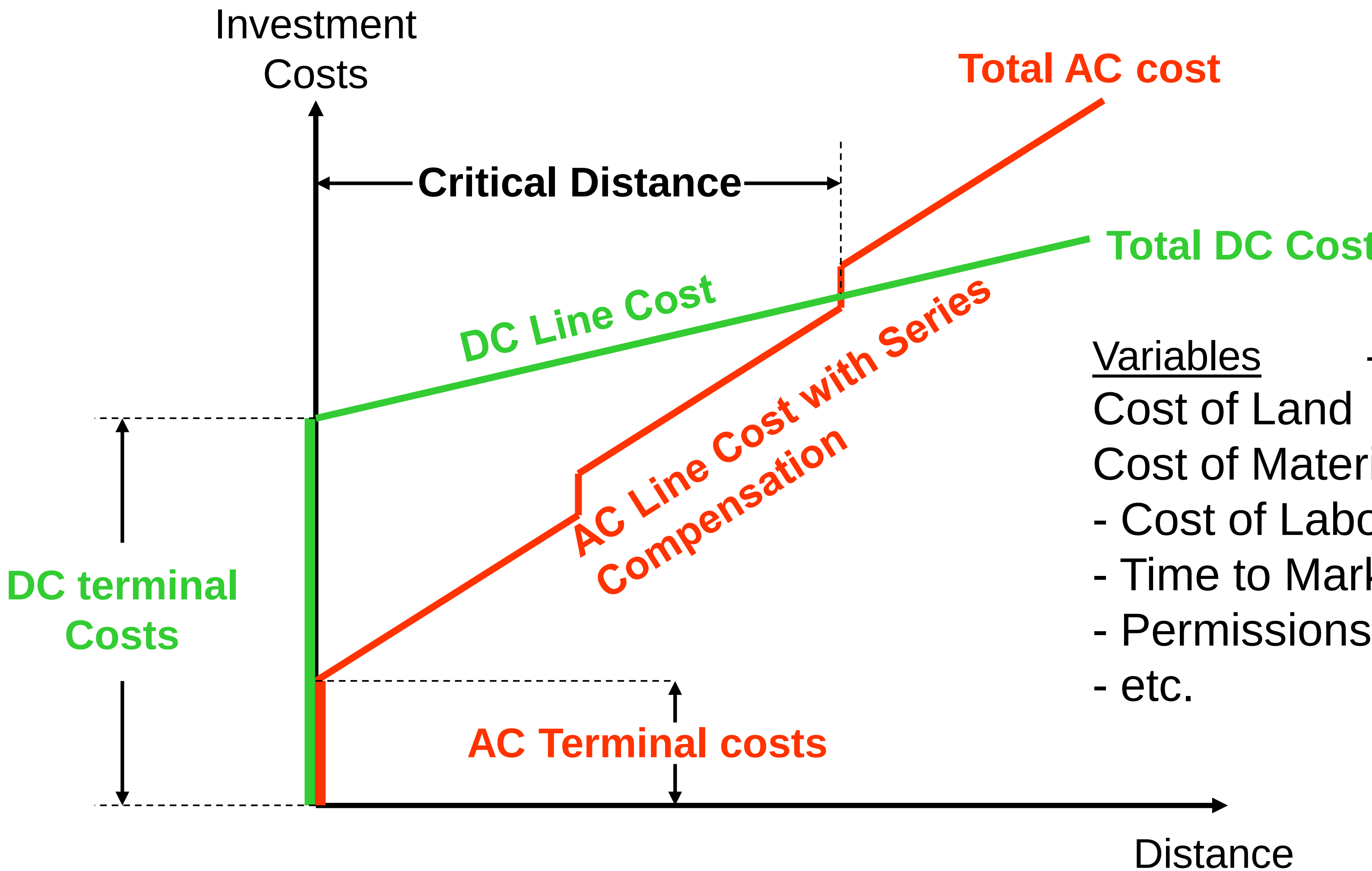
⇒ C& L can be compensated by reactors/capacitors or FACTS

⇒ **or by use of DC, which means $\omega = 2\pi\nu = 0$**





Investment cost versus distance for HVAC and HVDC

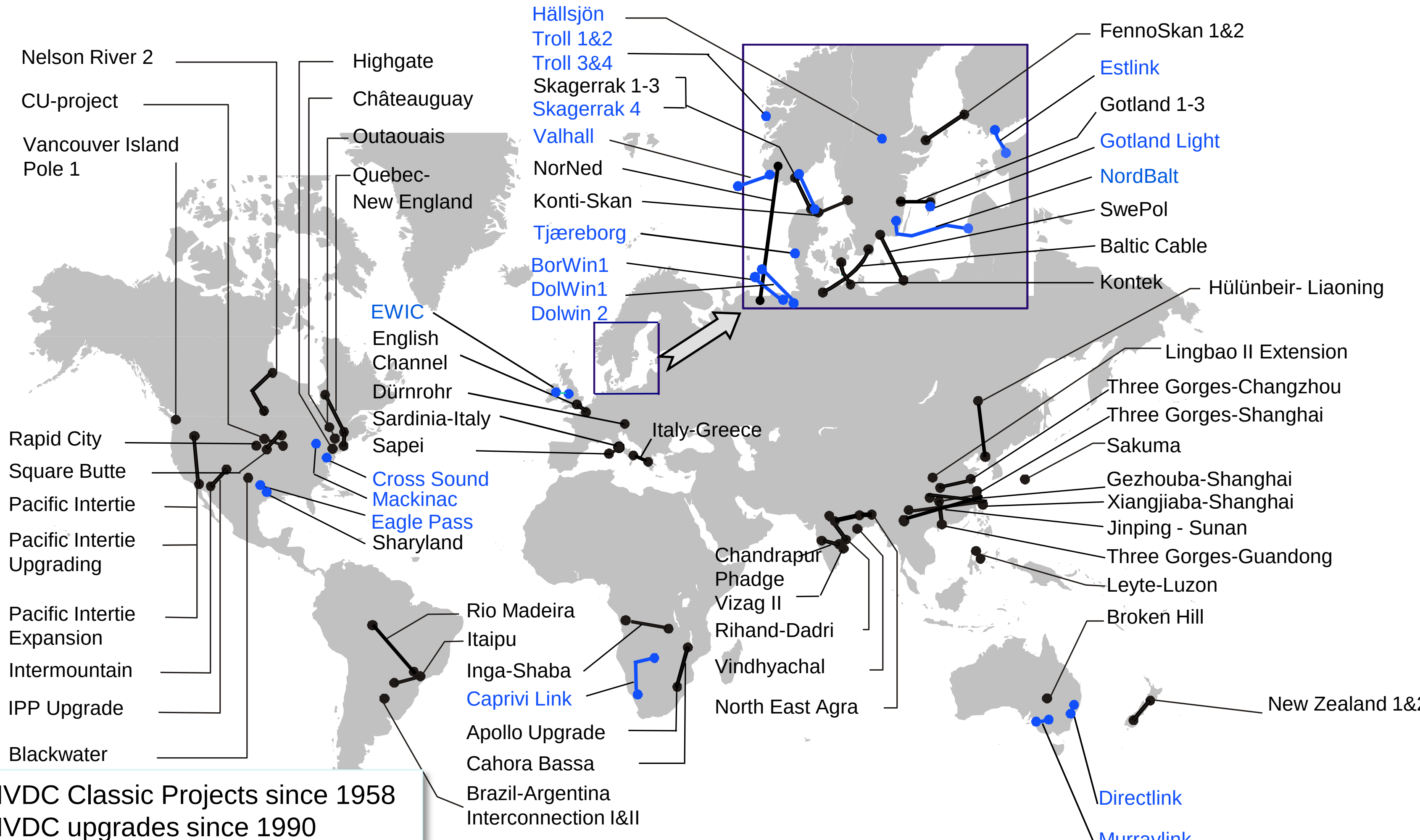


Variables -
Cost of Land -
Cost of Materials
- Cost of Labour
- Time to Market
- Permissions
- etc.

More than 50 years ago ABB broke the AC/DC barrier
Gotland 20 MW subsea link 1954

ABB has more than half of the 145 HVDC projects

The track record of a global leader



58 HVDC Classic Projects since 1958
14 HVDC upgrades since 1990
19 HVDC Light Projects since 1997

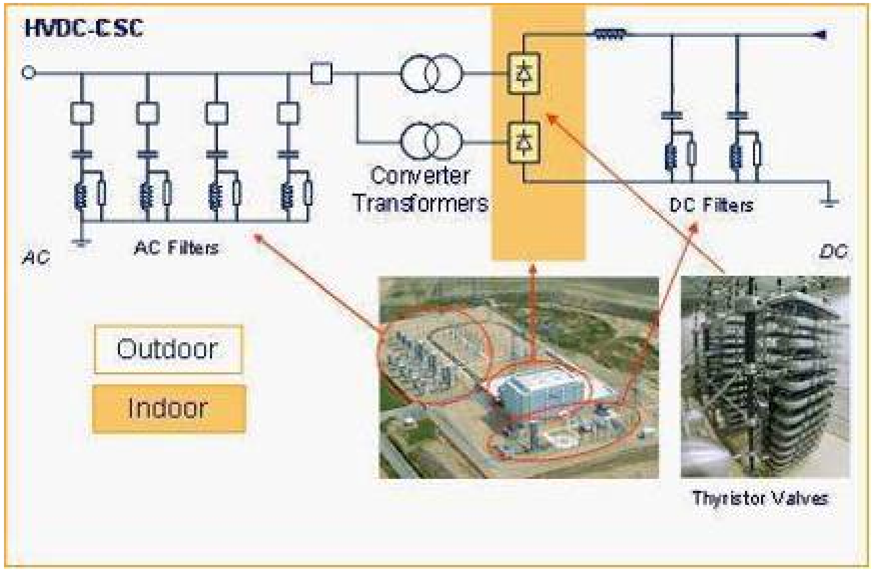
Development of HVDC applications

HVDC Classic

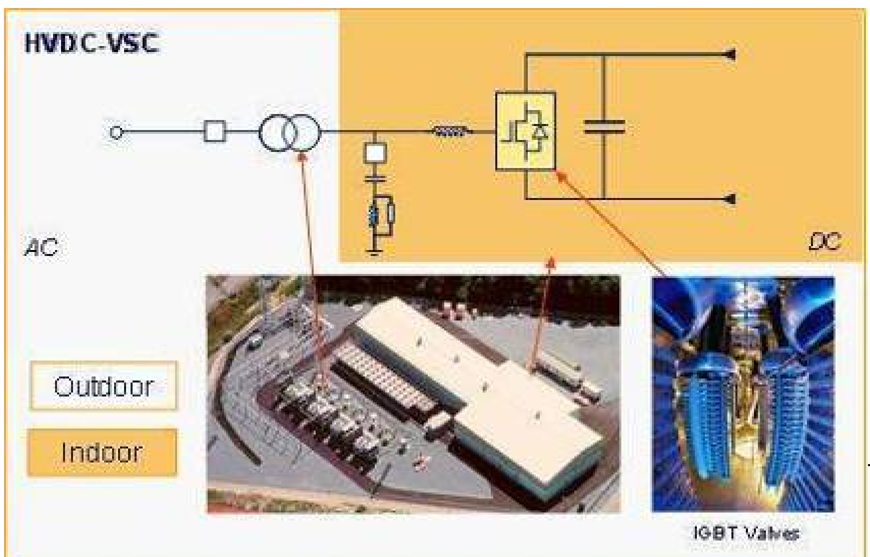
- Very long sub sea transmissions
- Very long overhead line transmissions
- Very high power transmissions

HVDC Light

- Offshore power supply
- Wind power integration
- Underground transmission
- DC grids



- HVDC Classic
  - Current source converters
  - Line-commutated thyristor valves
  - Requires 50% reactive compensation
  - Converter transformers
  - Minimum short circuit capacity > 2x converter rating

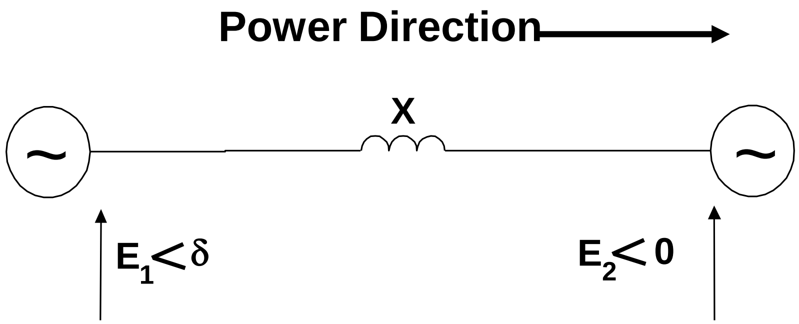


- HVDC Light
  - Voltage source converters
  - Self-commutated IGBT valves
  - Requires no reactive power compensation
  - “Standard” transformers
  - No minimum short circuit capacity, black start

Classic HVDC basic principles

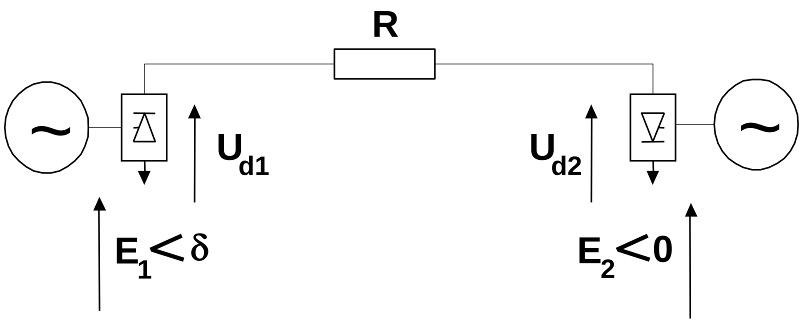
AC and DC transmission principles

HVAC



$$P = \frac{E_1 E_2}{X} sin(\delta)$$

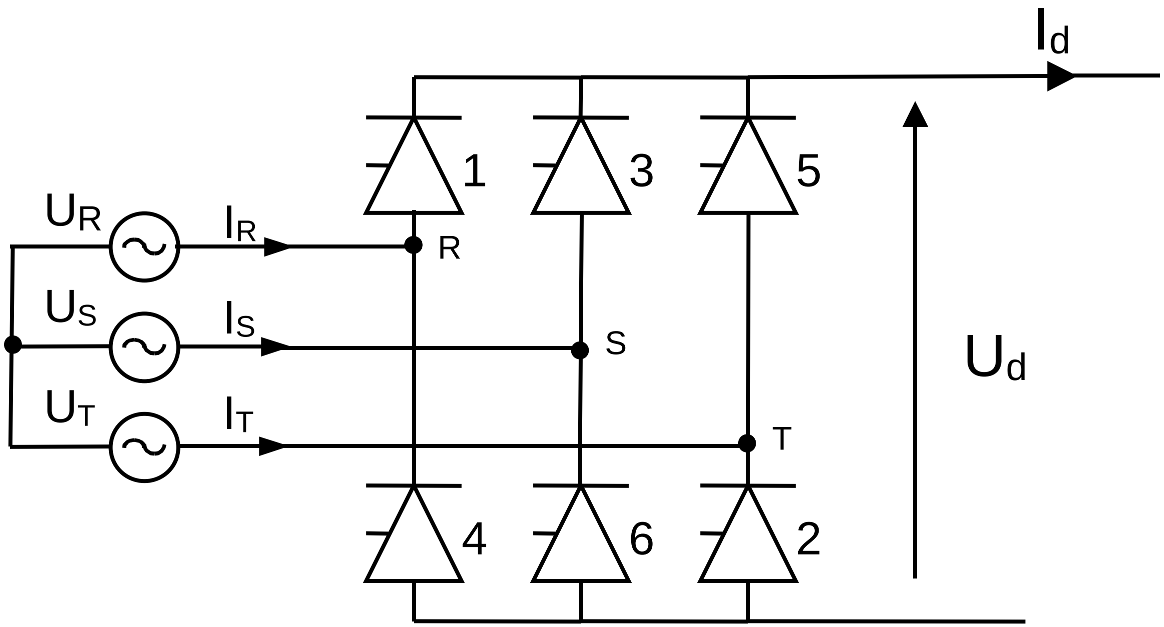
HVDC

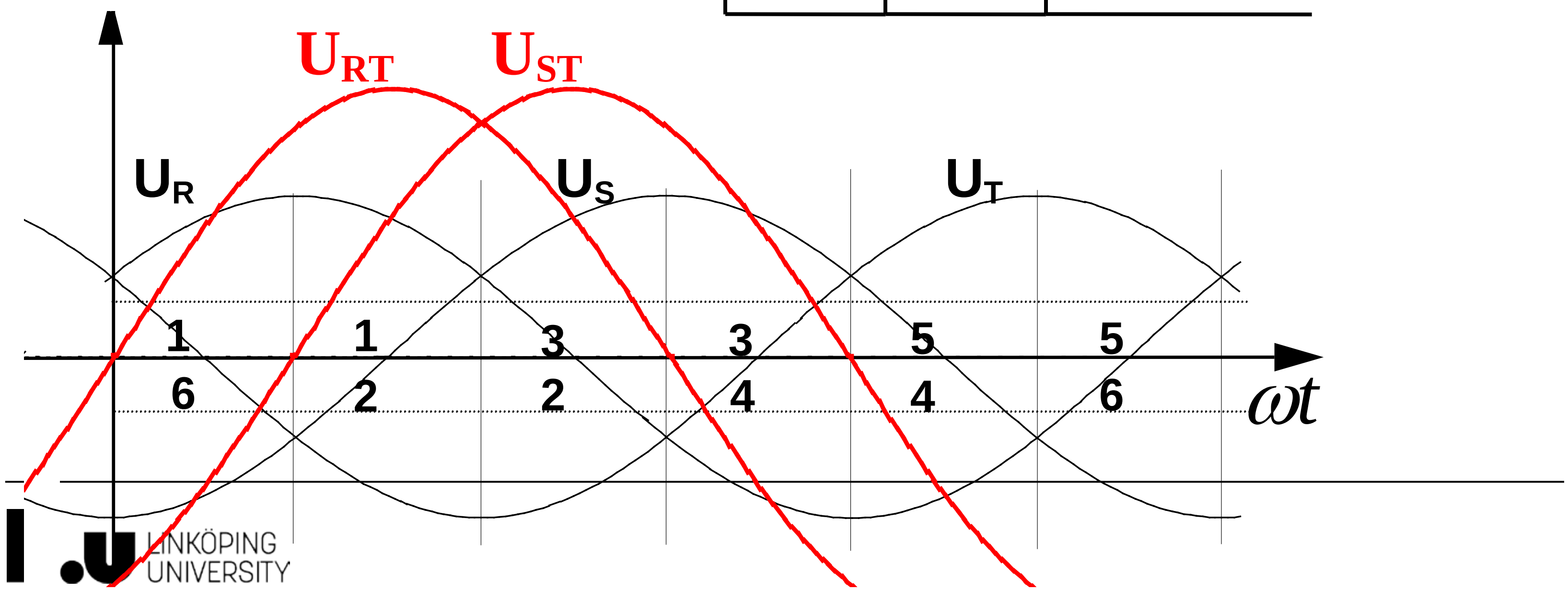


$$P = \frac{U_{d1}(U_{d1} - U_{d2})}{R}$$

Power flow independent from system angles

Principles of AC/DC conversion, 6-pulse bridge





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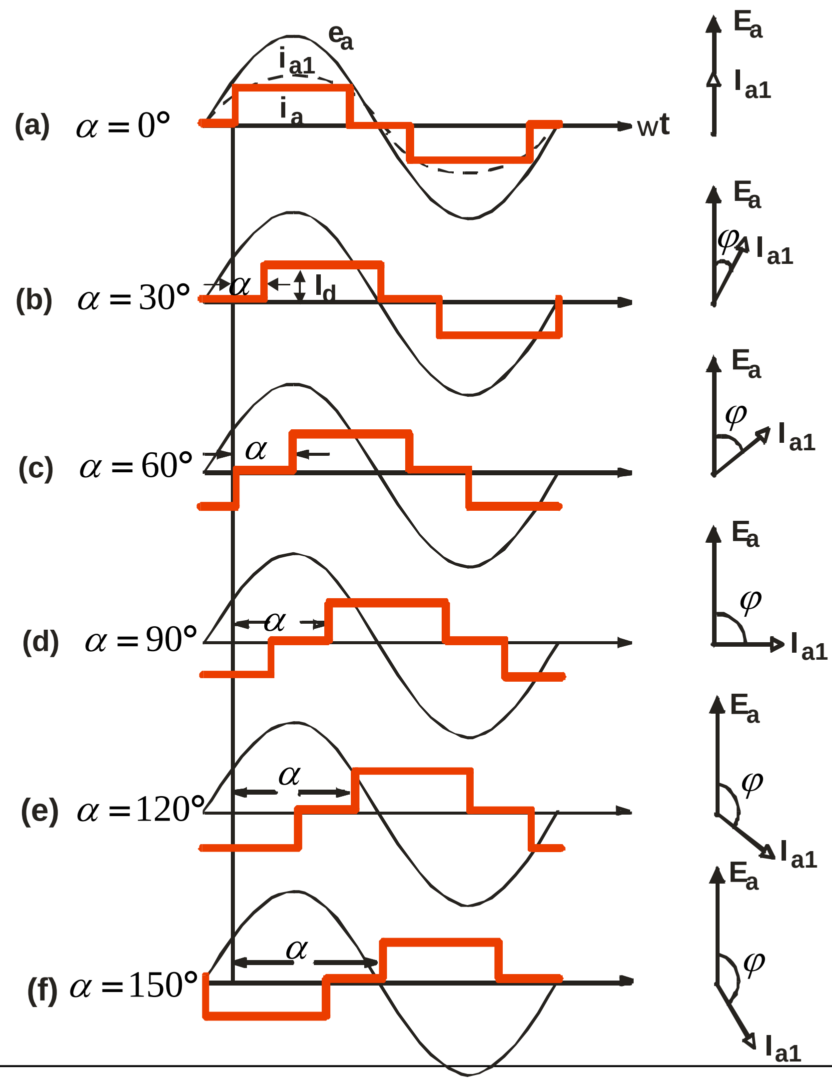
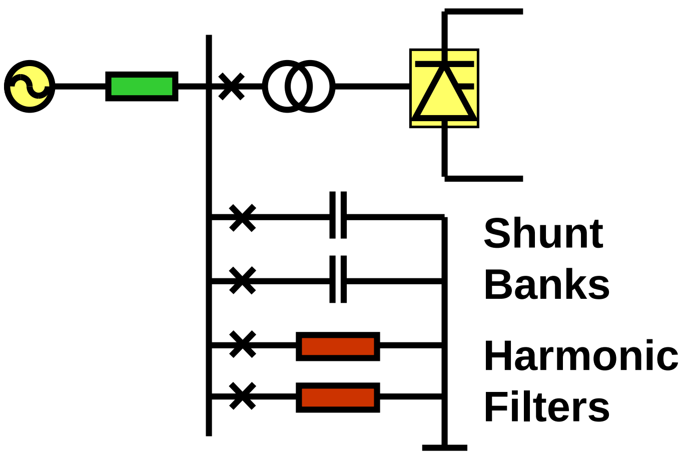
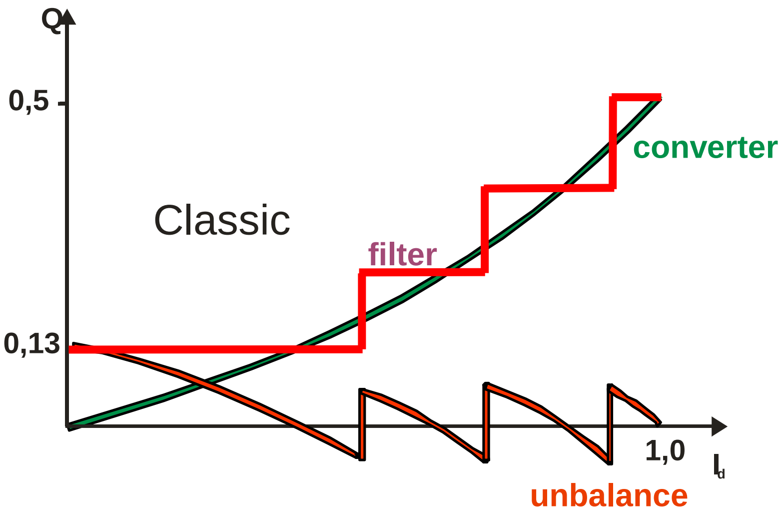
Relation between firing delay and phase displacement



Classic HVDC, Active vs Reactive Power

- **How the Reactive Power Balance varies with the Direct Current for a Classic Converter ....**

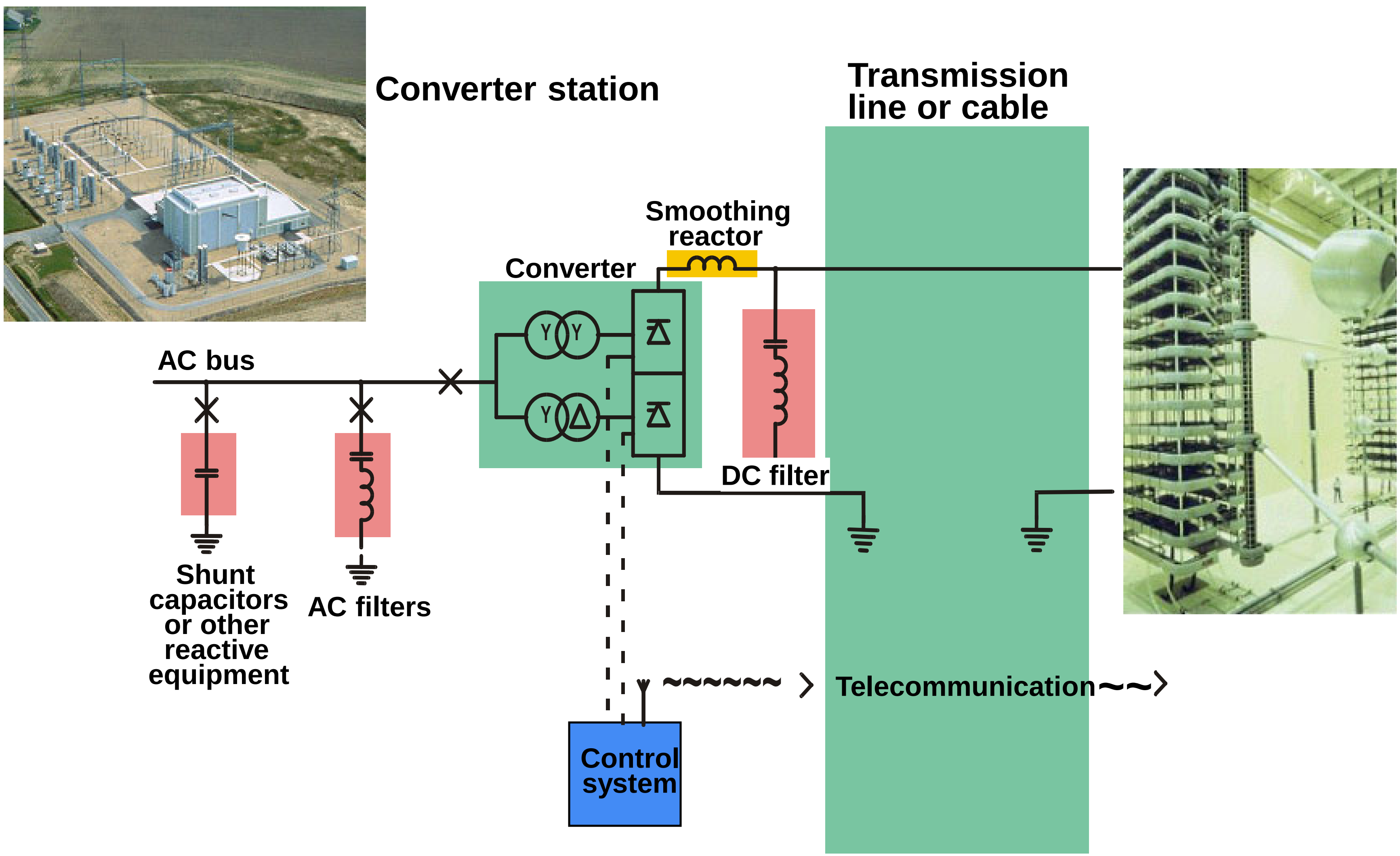




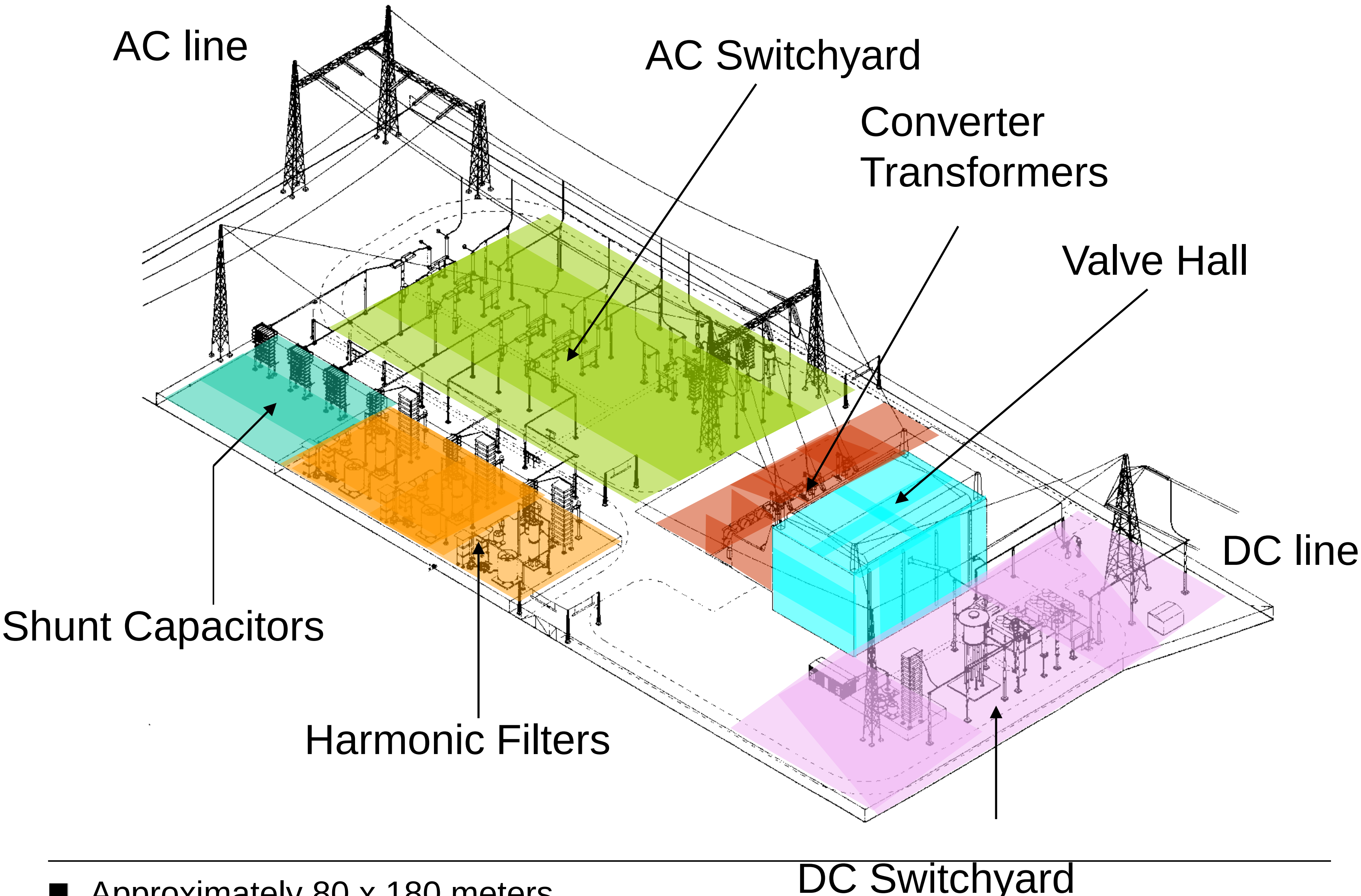
Baltic Cable 600 MW HVDC link

▪L36994

The HVDC Classic Monopolar Converter Station



Monopolar Converter station, 600 MW



Approximately 80 x 180 meters

Longquan, China
HVDC Classic

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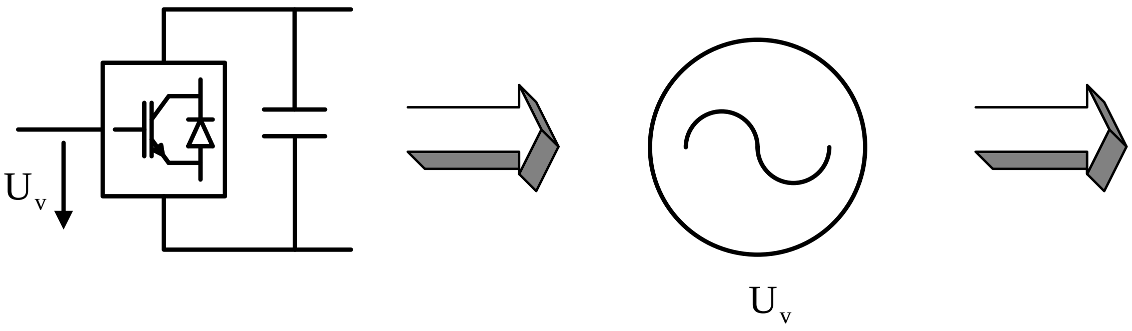
VSC HVDC
basic principles

Introduction

1. Why VSC HVDC

Particular advantages with VSC HVDC

1. Voltage source functionality



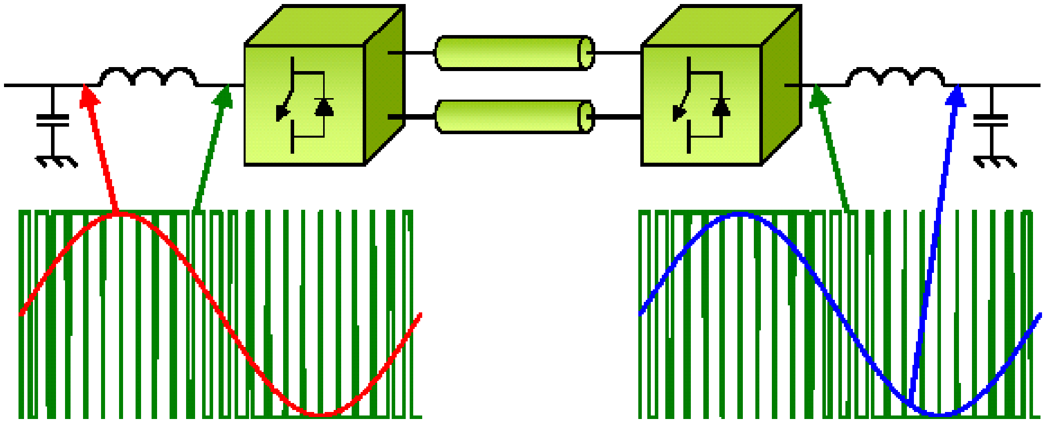
- **Rapid, <u>independent</u> control of active <u>and reactive</u> power**
- **No need for a strong grid**

Introduction

1. Why VSC HVDC

Particular advantages of VSC HVDC

3. Pulse width modulation of AC voltages



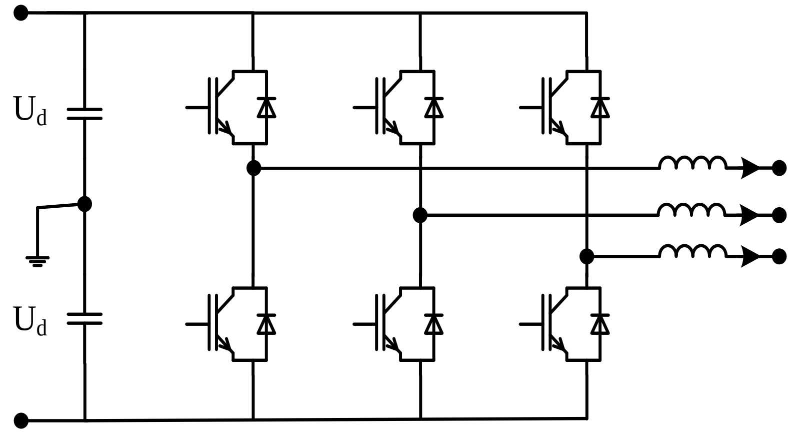
Small filters, both on AC and DC side

VSC HVDC basic principles

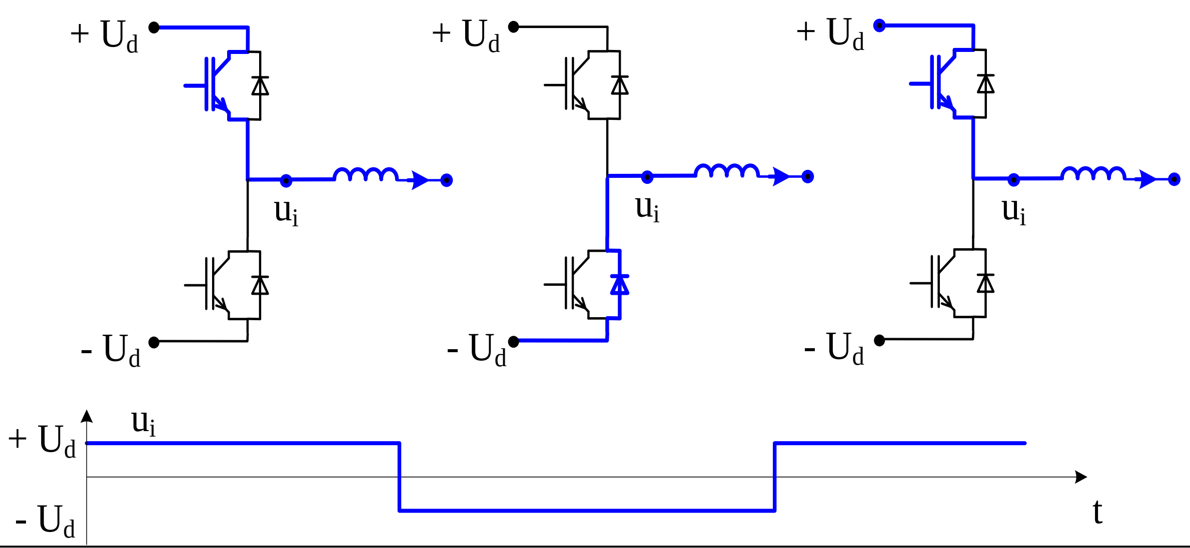
2. VSC converter topologies

Two-level voltage source converter.

*Converts a DC voltage into a three-phase AC voltage by means of switching between **two** voltage levels.*



Basic operation of a phase leg:



VSC HVDC basic principles

2. VSC converter topologies

Multilevel topologies - basics

+ Phase voltages **are multi-level (>2).**

+ Pulse number and switching frequency are decoupled**.**

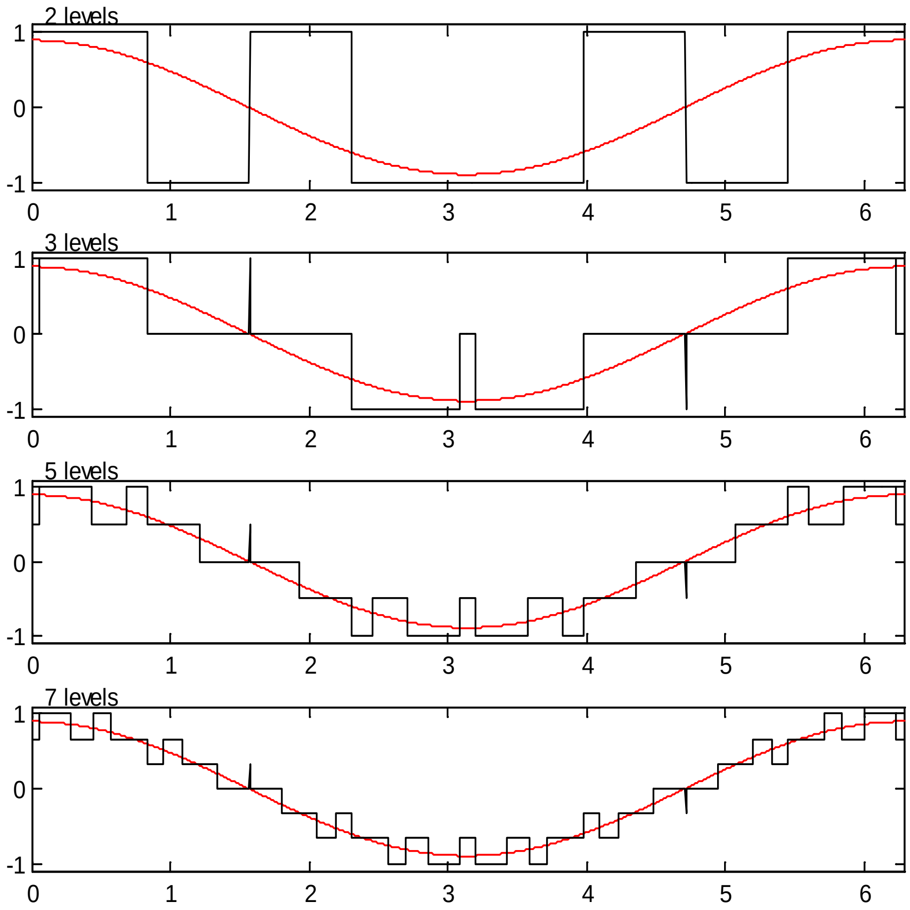
+ The output voltage swing is reduced **– less insulation stress**

+ Series-connected semiconductors **can be avoided for high voltage applications**

- More complicated **converter topologies are required**

- More semiconductors required

Typical applications: high-power converters **operating at medium or high voltage.**

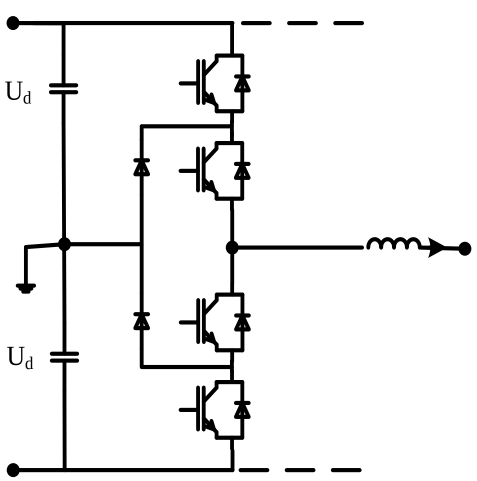


VSC HVDC basic principles

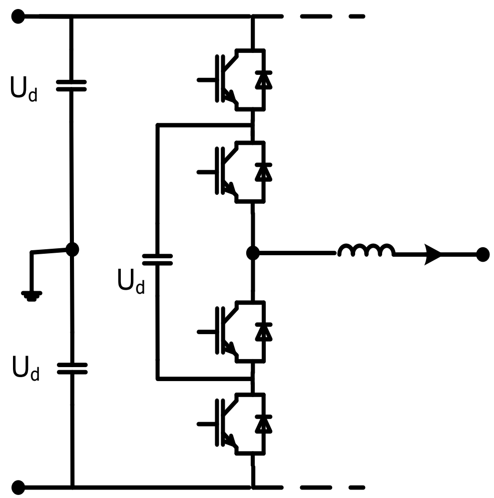
2. VSC converter topologies

Multilevel converter topologies

Neutral point clamped (NPC) topologies



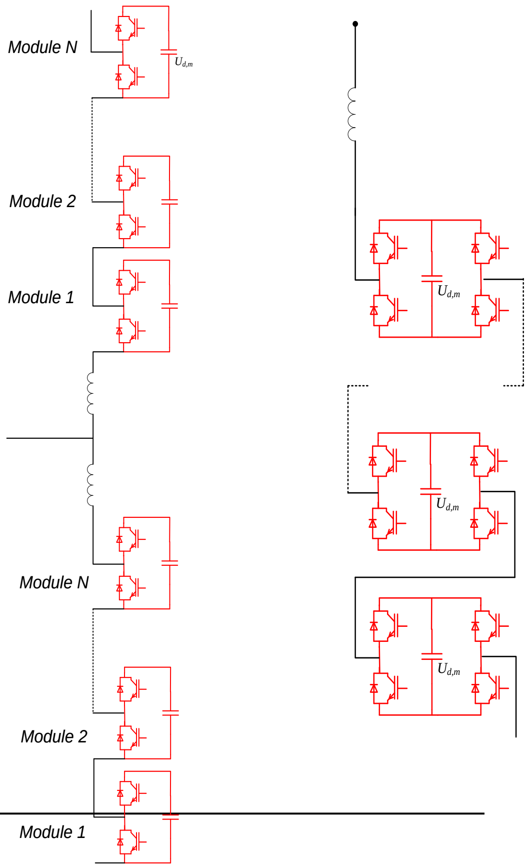
Flying capacitor topologies



Cascaded topologies

Modular Multilevel Converters (MMC)

Half-bridge and full-bridge variants



One phase leg, or equivalent, shown in each case

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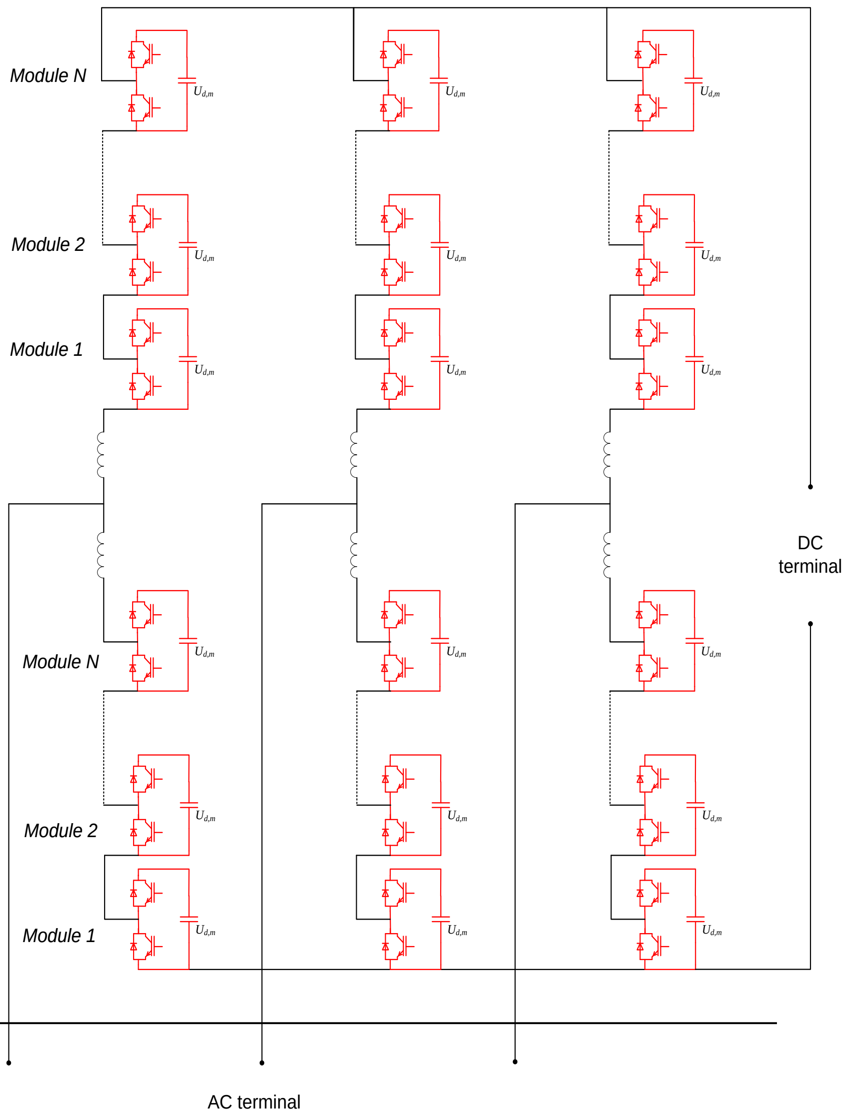
VSC HVDC basic principles

Modular multi-level converter (MMC)

Modular multi-level converter (MMC)

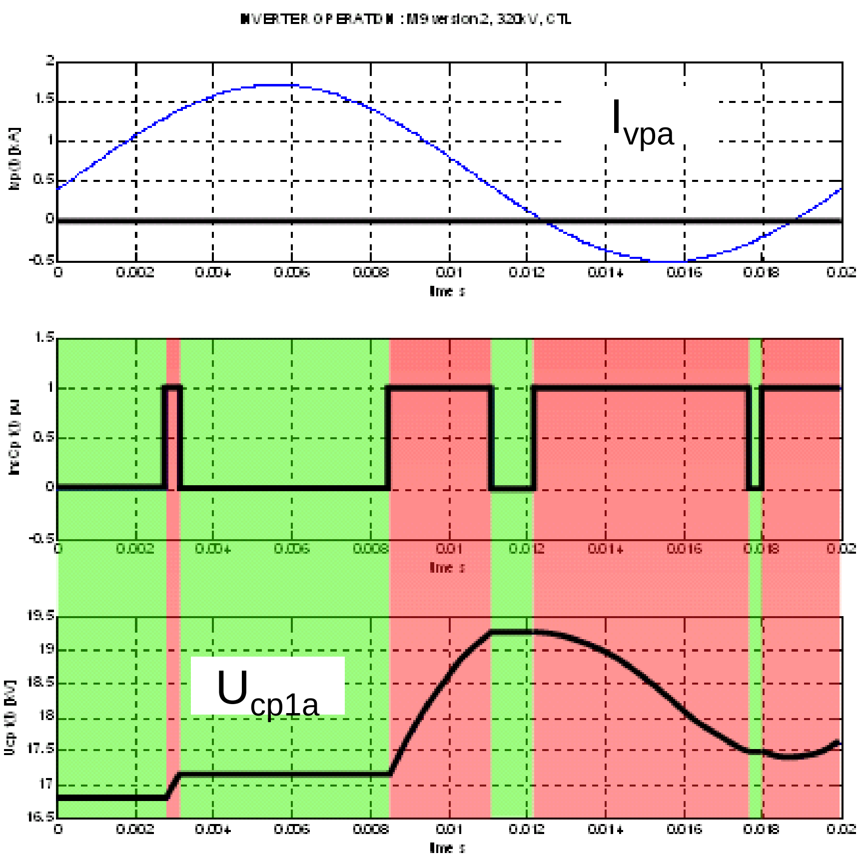
Prof. Marquardt, Univ. Munich

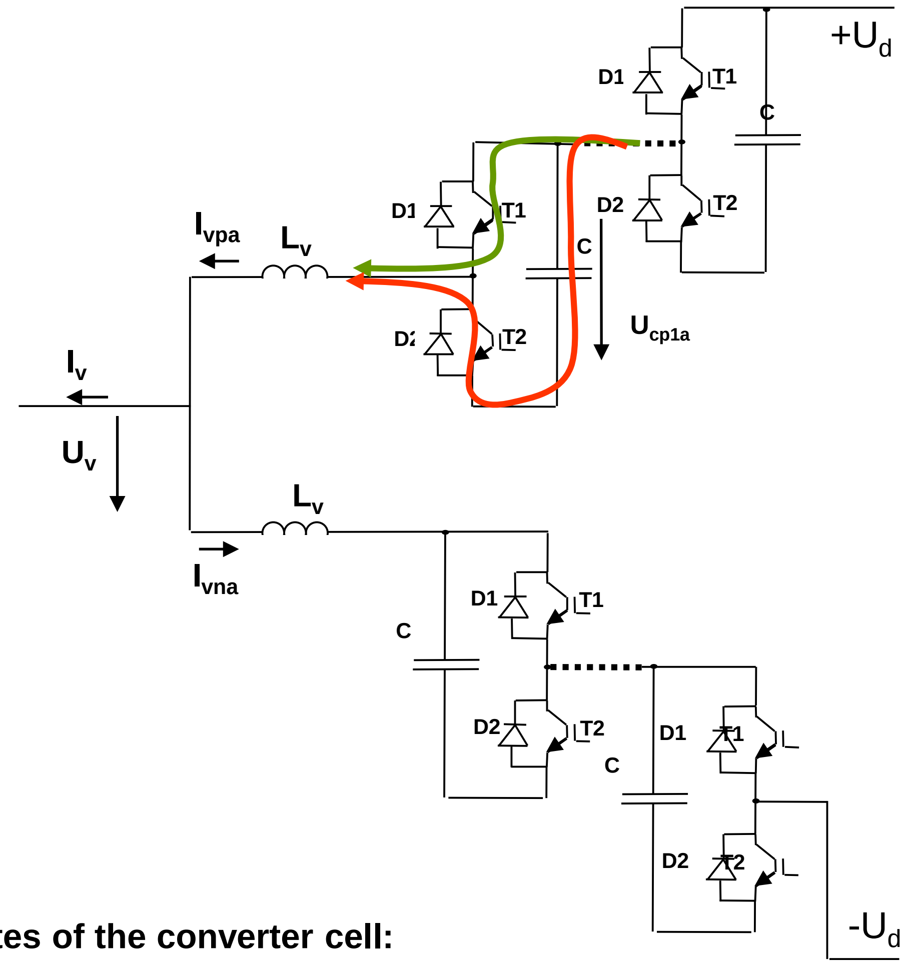
- **DC capacitors distributed in the phase legs**
- **DC capacitors handle fundamental current**
- **Scalable with regard to the number of levels**
- **Twice the total blocking voltage required (twice no of semiconductor devices) compared to two-level converter**
- **Redundancy possible by shorting failing cells**



VSC HVDC basic principles

MMC-converter, switching principle





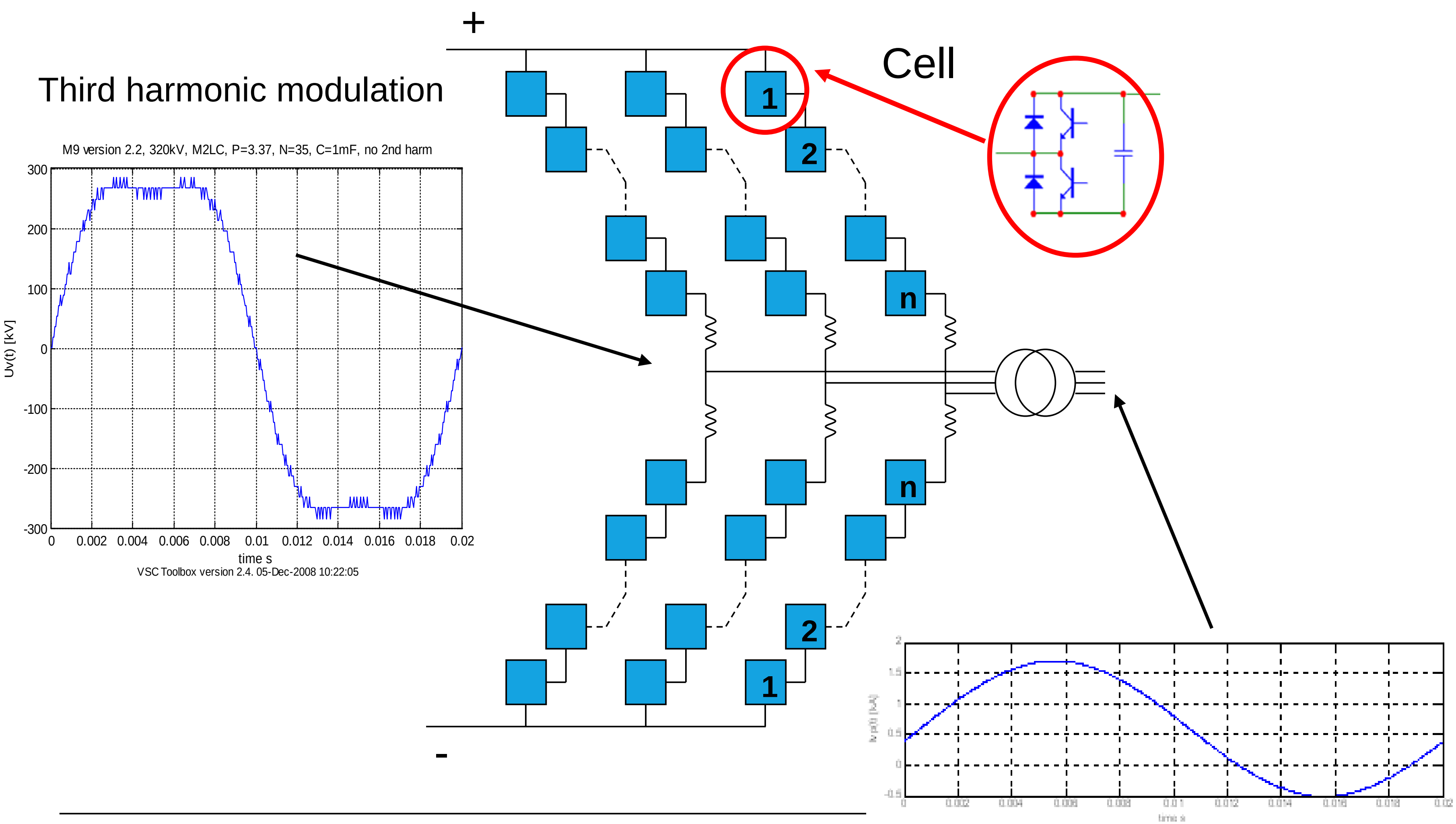
Three operating states of the converter cell:

- Bypass mode. Cell capacitor is bypassed. (Green curve)
- Inserted mode. Cell capacitor is inserted and giving contribution to converter output voltage
- Blocked mode. All IGBTs non-conducting

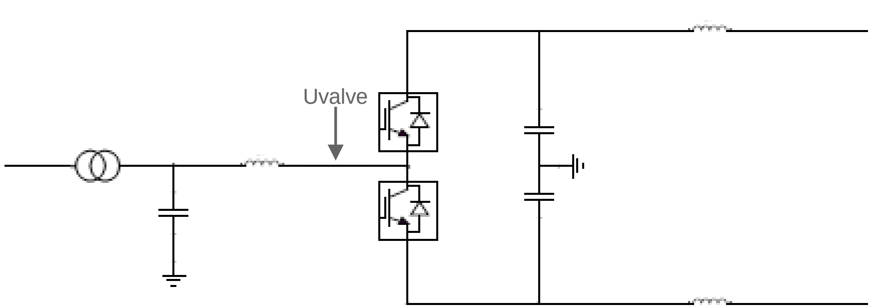
VSC HVDC basic principles

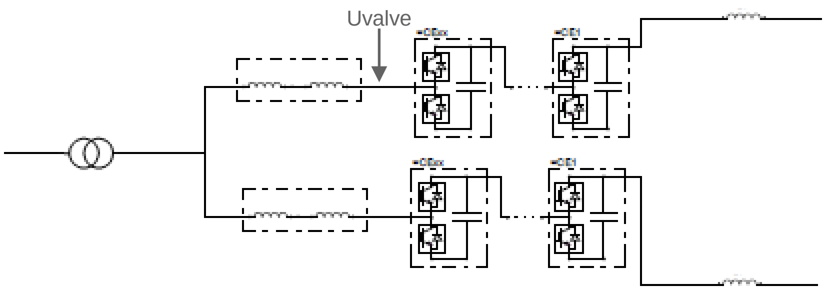
MMC-converter, Output voltage

Third harmonic modulation

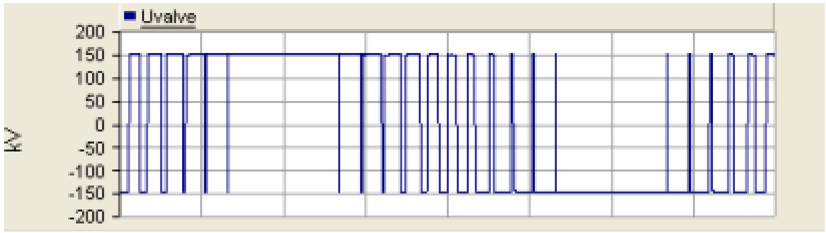


VSC performance – Switching Principle

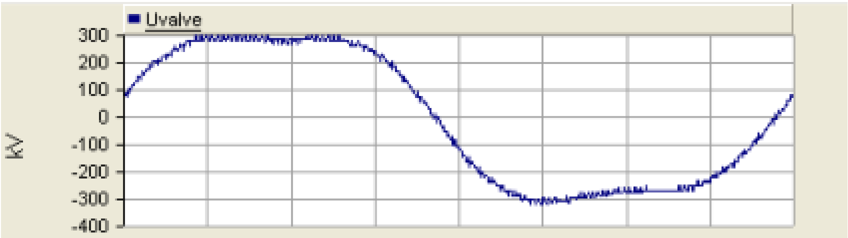




2-level ±150 kV_{dc}

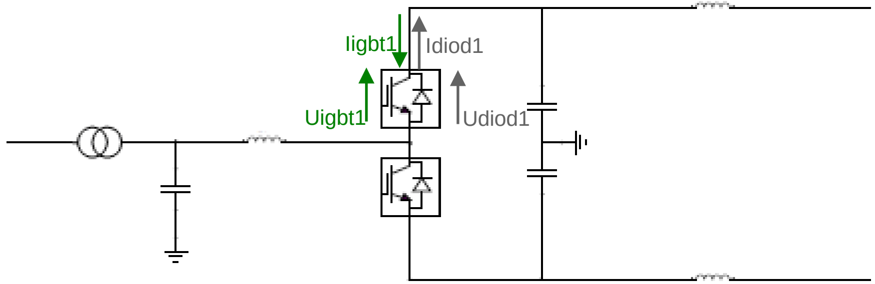


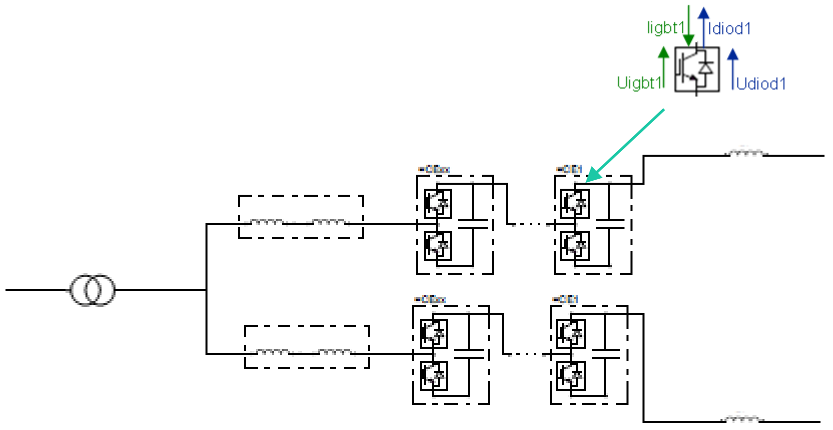
MMC ±320 kV_{dc}



VSC performance

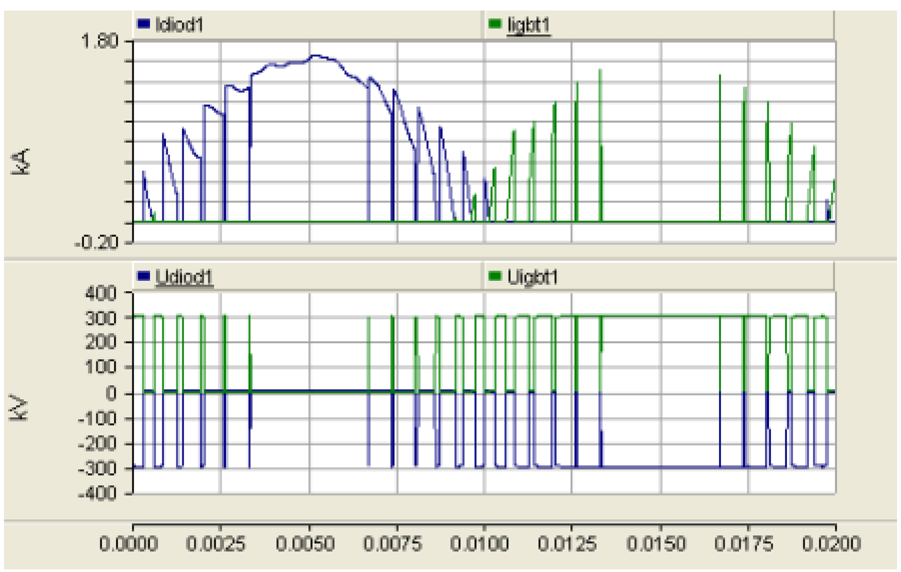
– Valve voltages and currents



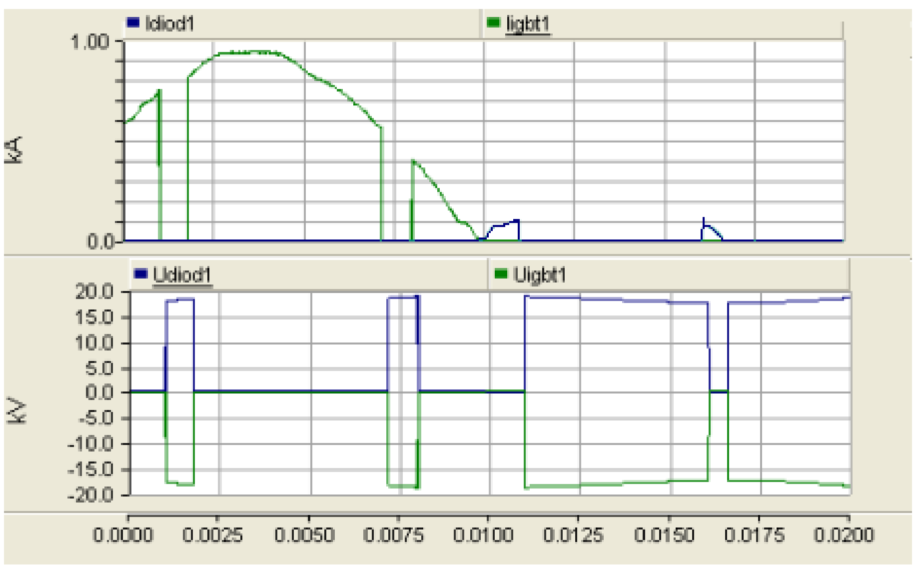


Reduced losses

2-level

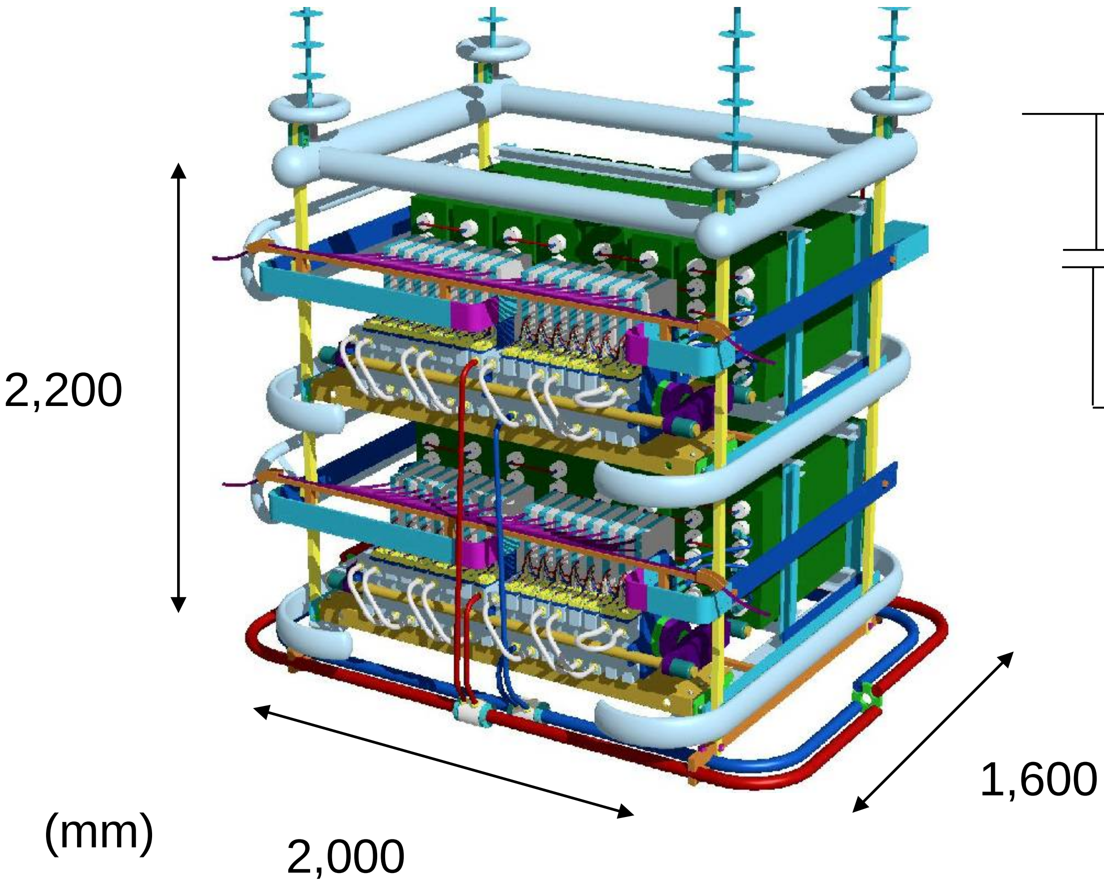


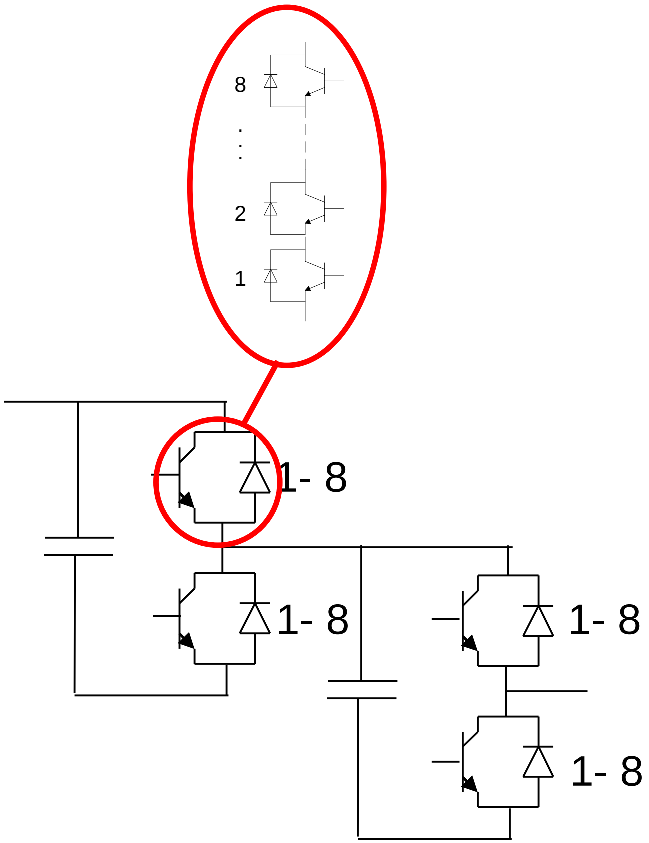
MMC



HVDC Light Generation 4

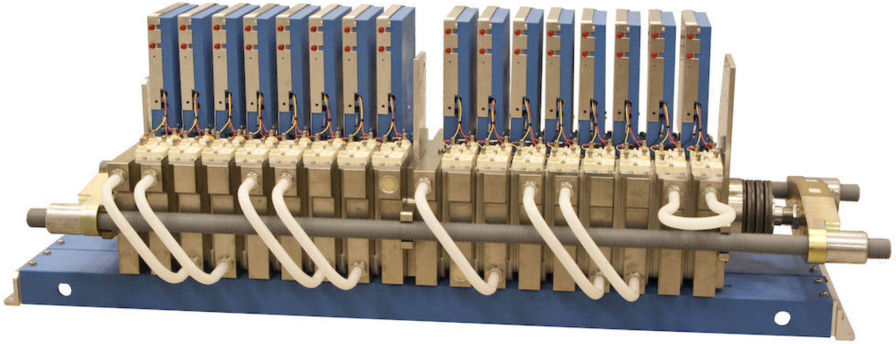
Double cell

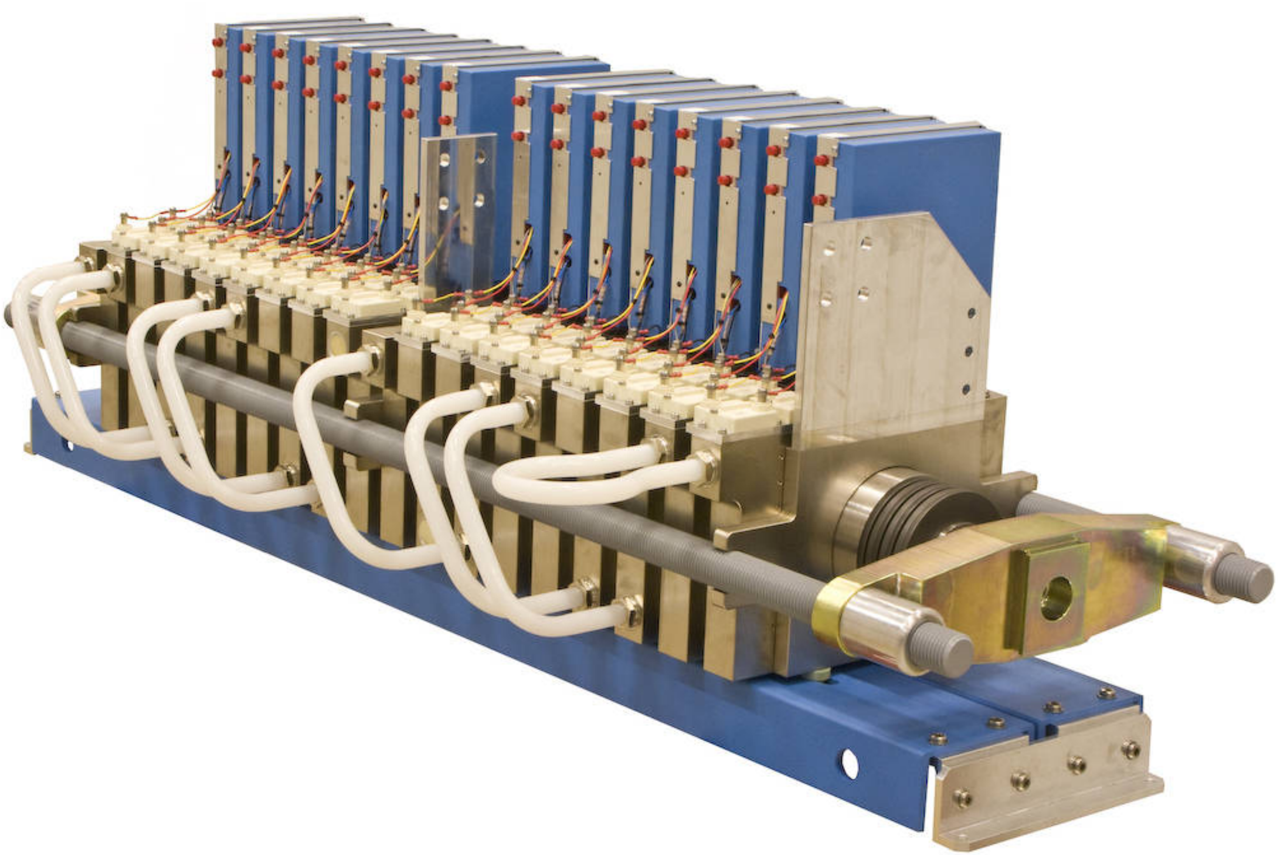




Mass 3,000 kg

IGBT Module

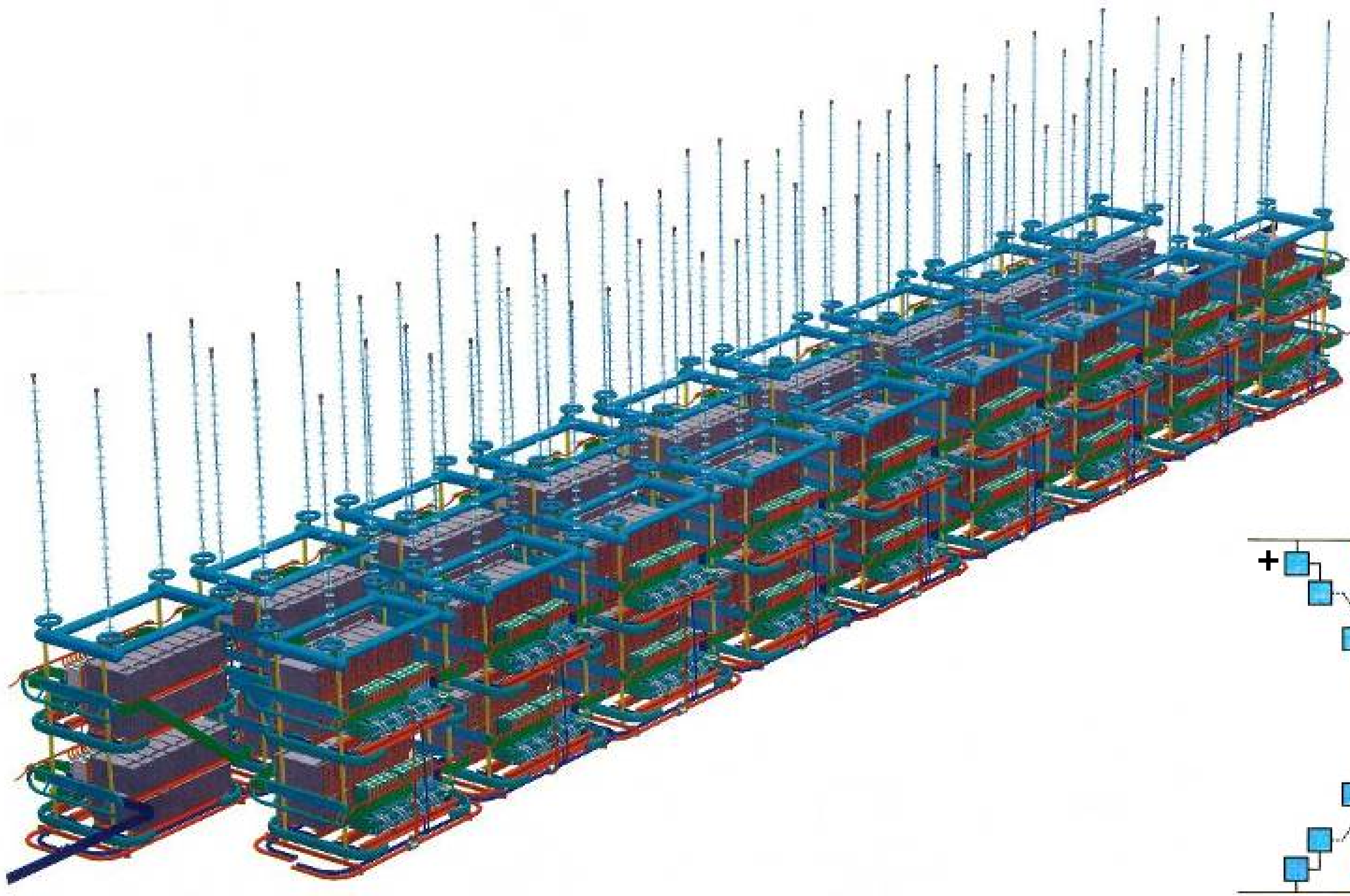


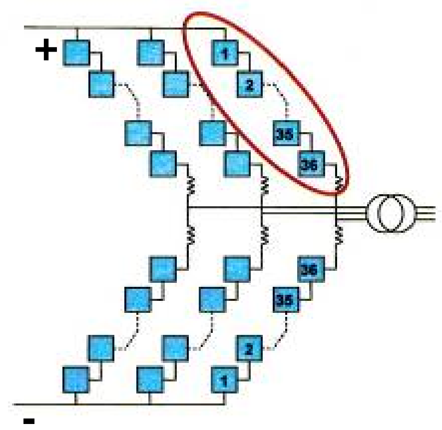


IGBT inner structure

HVDC Light Generation 4

Valve arm





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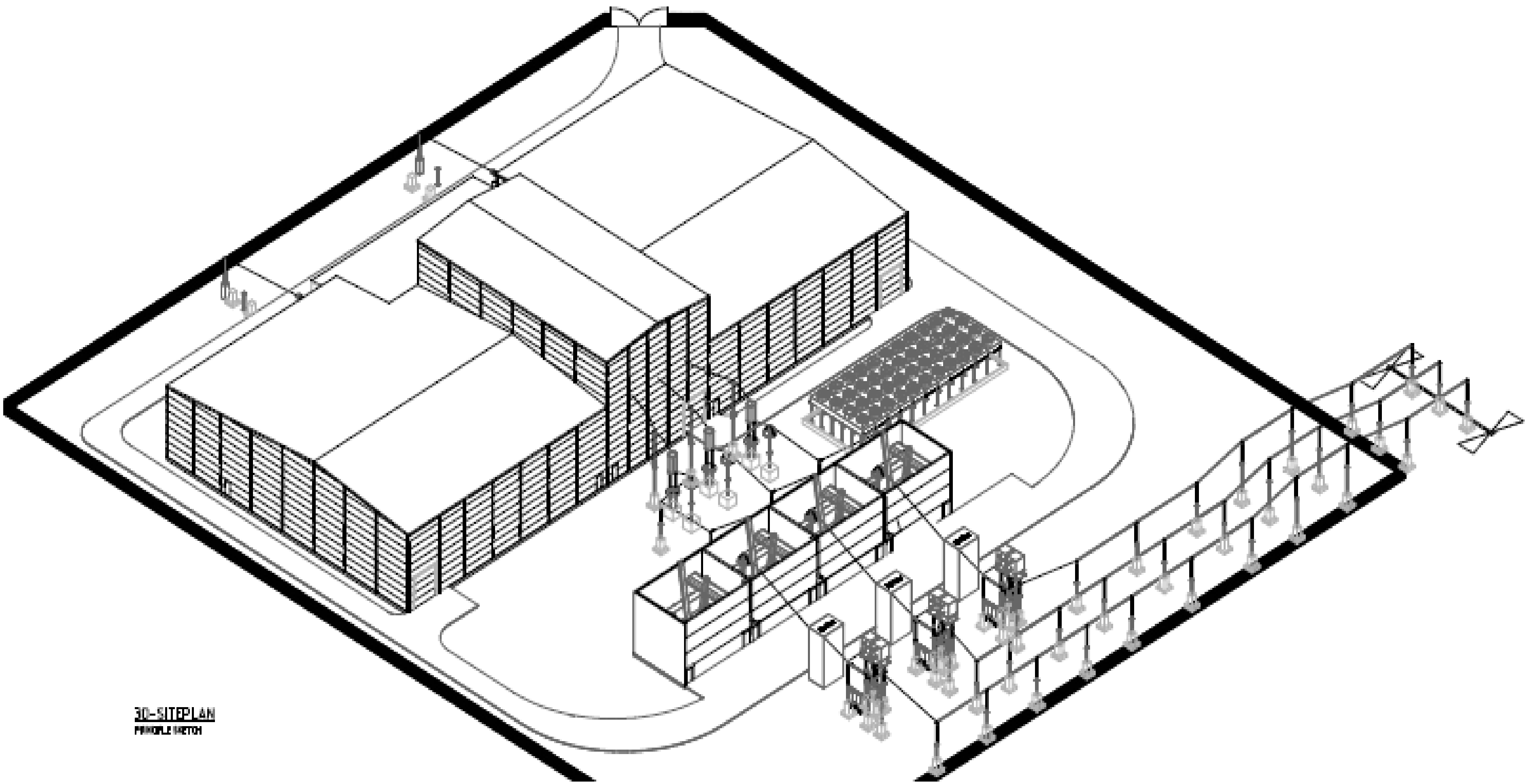
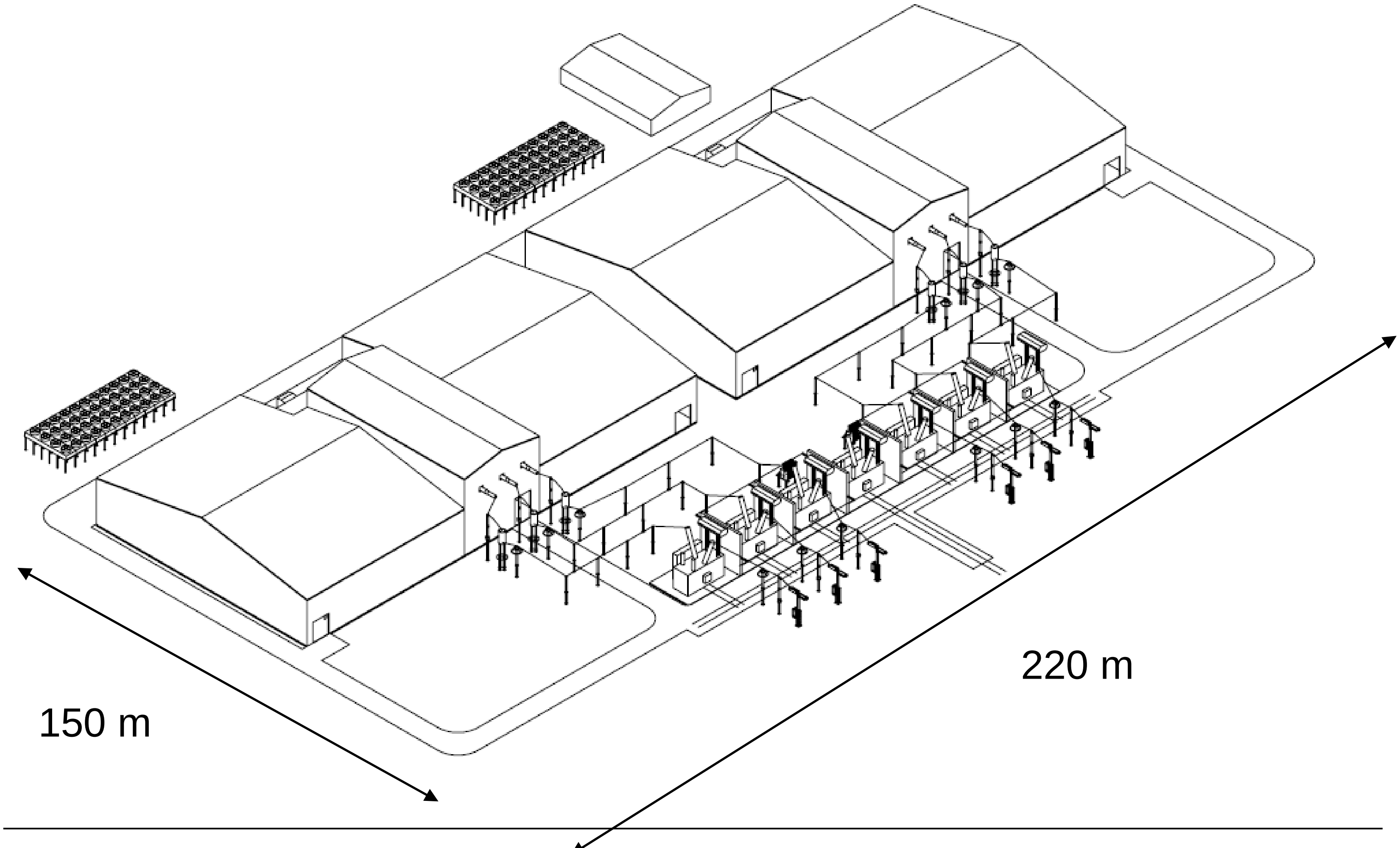
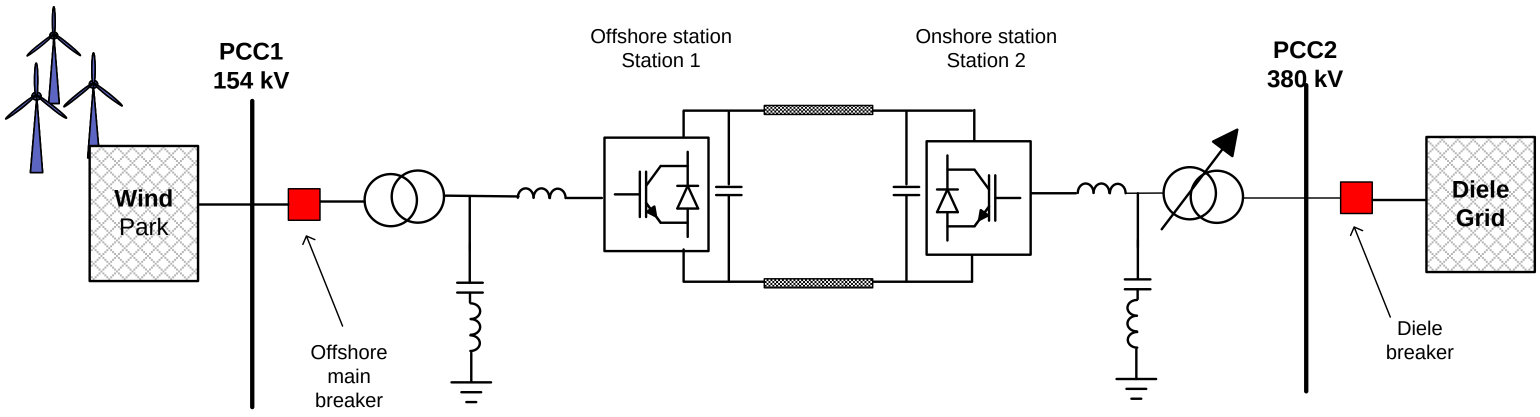
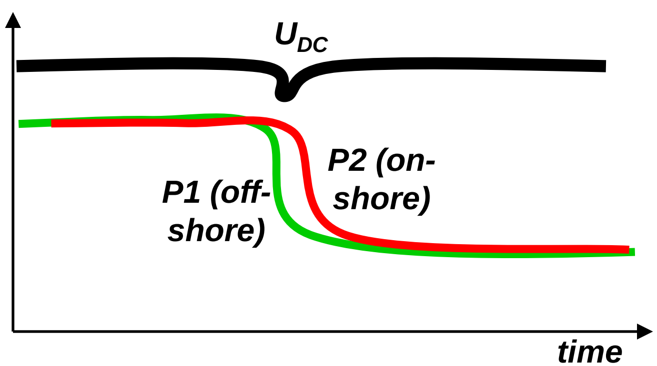

3D-SITEPLAN


150 m
220 m

Normal operation



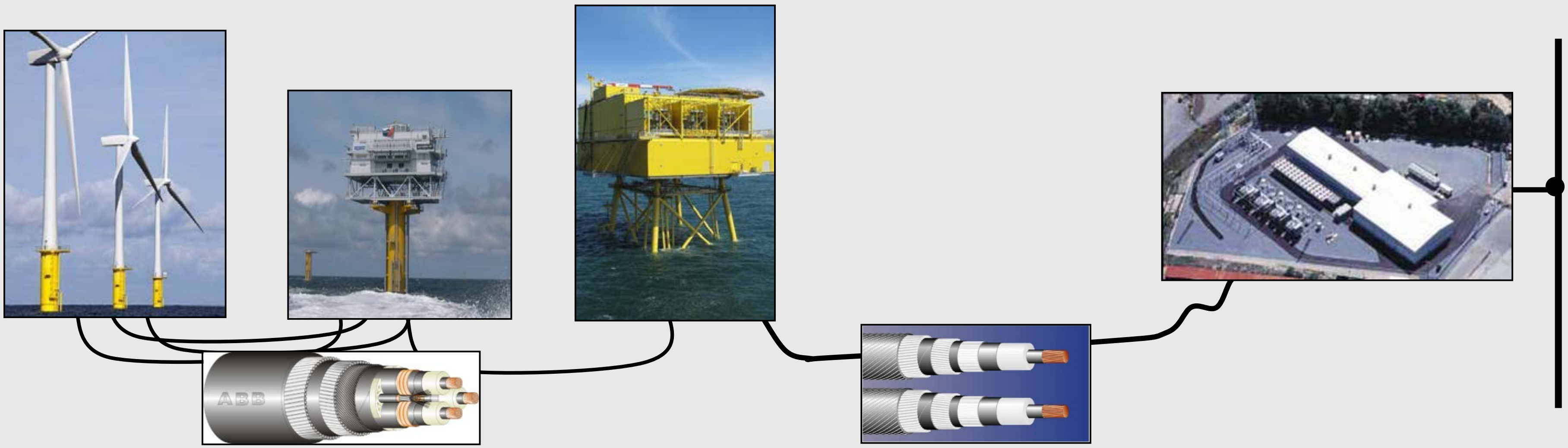
1. **Off-shore converter in voltage and frequency control.**
2. **On-shore converter in dc-voltage and reactive power control.**
3. **Windpark power reduction,**
4. **Off-shore converter power (P1) drops, since ac-voltage control results in power tracking**
5. **Instantaneous dc-power unbalance (P1-P2) < 0 ⇒ dc-voltage drop**
6. **On-shore dc-voltage control quickly reduces power (P2) to restore nominal dc-voltage and power balance.**



VSC in the power grid Wind applications

Overview

Offshore HVDC wind power connectors



100 – 300 MW: ± 80 kV HVDC Light (VSC)
300 – 500 MW: ± 150 kV HVDC Light
500 – 1000 MW: ± 320 kV HVDC Light

VSC technology for compact solutions. ABB with 10 years experience (13 references)

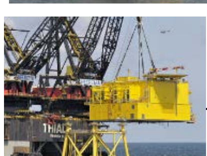
Borwin 1, Dolwin 1 & 2 Offshore Point-to-Point

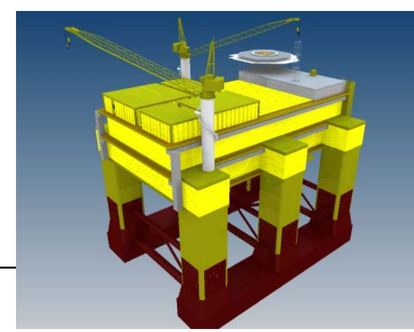
Why HVDC Light: Length of land and sea cable

Main data	**Borwin 1**	**Dolwin 1**	**Dolwin 2**
In operation:	2010	2013	2015
Power rating:	400 MW	800 MW	900 MW
AC Voltage Platform: Onshore	170 kV 380 kV	155 kV 380 kV	155 kV 380 kV
DC Voltage:	±150 kV	±320 kV	±320 kV
DC underground cable: DC submarine cable:	2 x 75 km 2 x 125 km	2 x 75 km 2 x 90 km	2 x 45 km 2 x 90 km

DOLWIN1: efficiently integrating power from offshore wind

DOLWIN alpha platform loadout





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