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Power Electronic Converters for HVDC Applications

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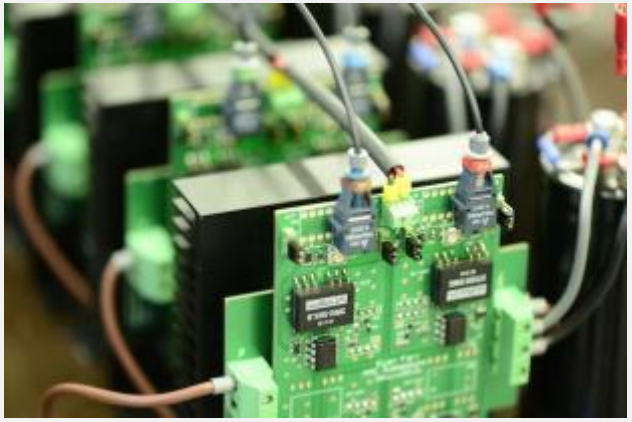
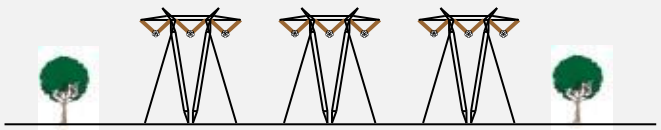
Introduction

- Power Electronics for HVDC Power System Applications
  - Applications in Renewable Energy
    - Offshore wind power
    - European DC Grid
  - Power Converter topology options
    - MMC
    - Series Hybrid – Alternate Arm Converter
    - Parallel Hybrid

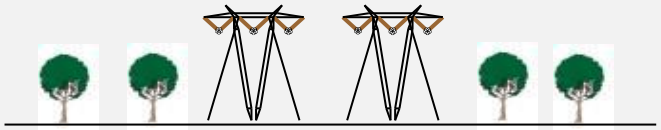
HVDC Applications



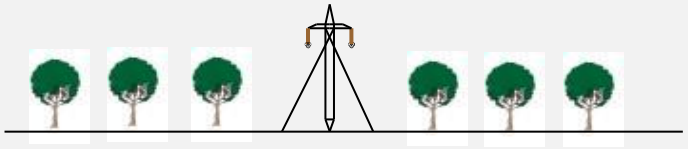
AC or DC Transmission



Traditional overhead line with AC



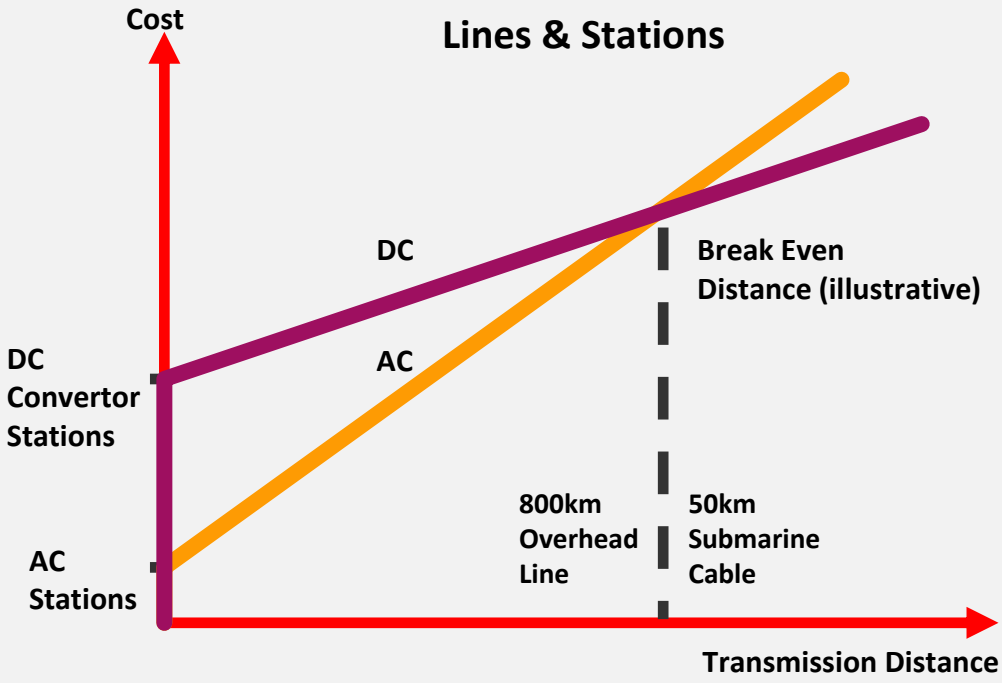
Overhead AC line with FACTS



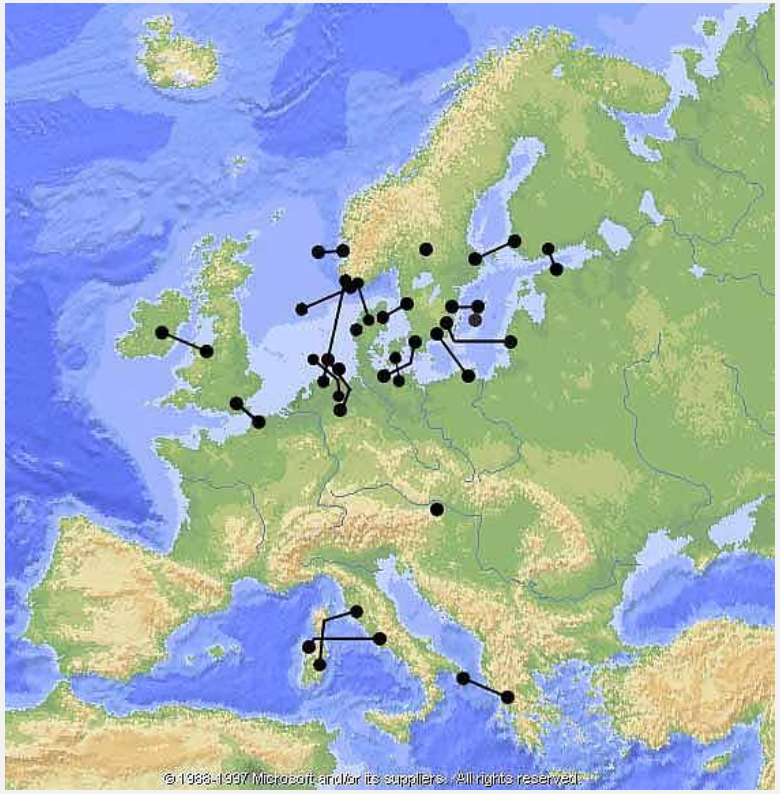
HVDC overhead line

- Cost of construction
  - Components, space, transportation,…
- Efficiency of operation
  - Losses, downtime,…
- Environmental impact
  - Location, visual impact, resources,…

- HVDC Applications
  - Offshore wind farms
  - Remote generation
    - Hydro, wind, wave, solar….
  - Country interconnections
    - Example: UK-France



AC or DC Transmission



- Cost of construction
  - Components, space, transportation,…
- Efficiency of operation
  - Losses, downtime,…
- Environmental impact
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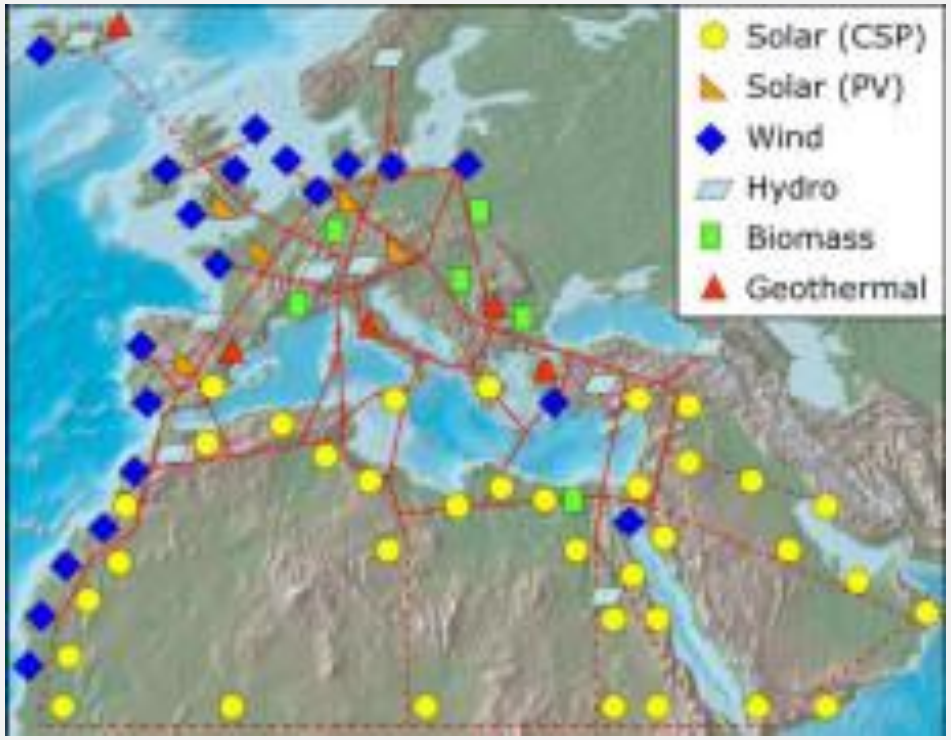
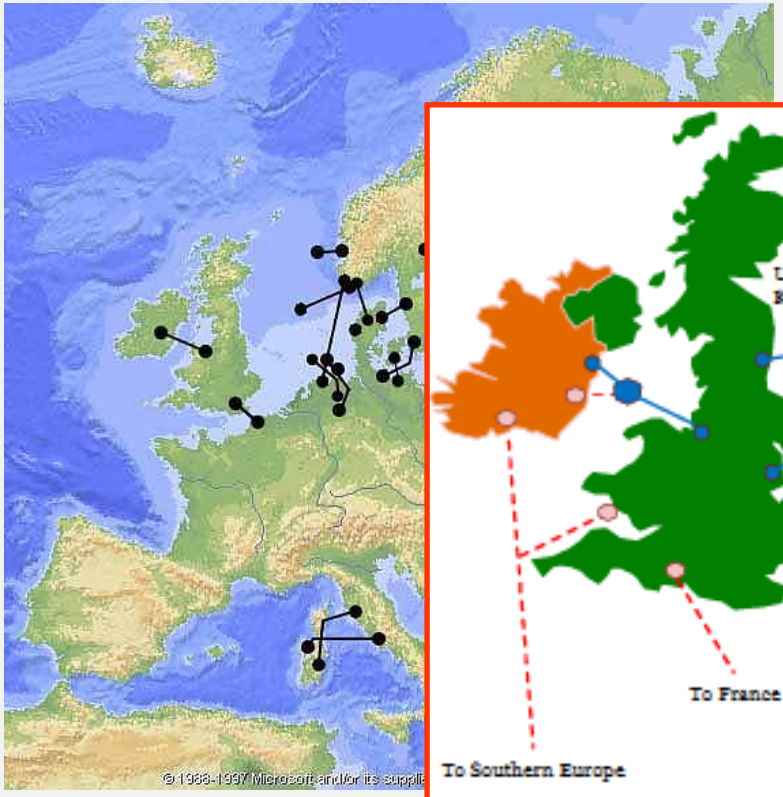
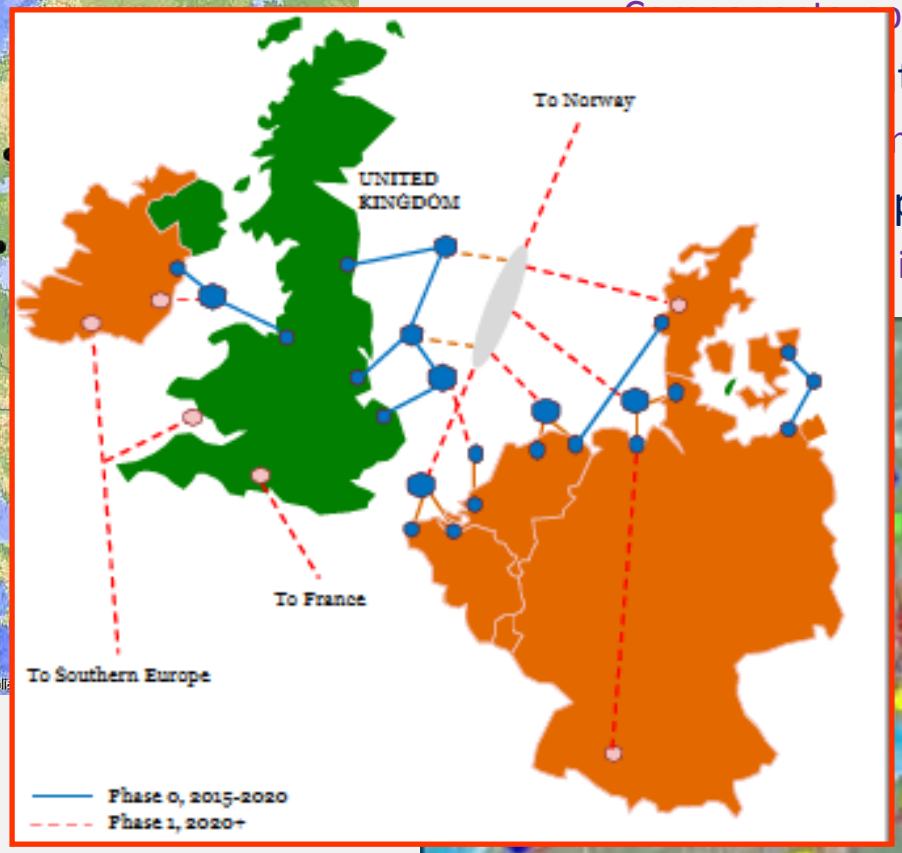
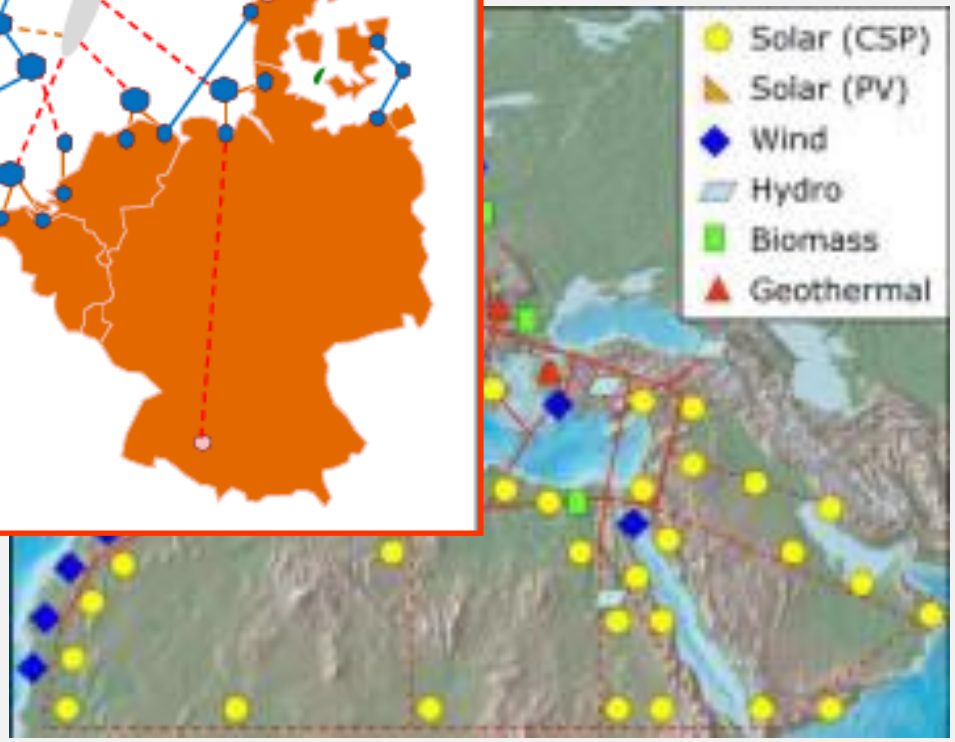


AC or DC Transmission

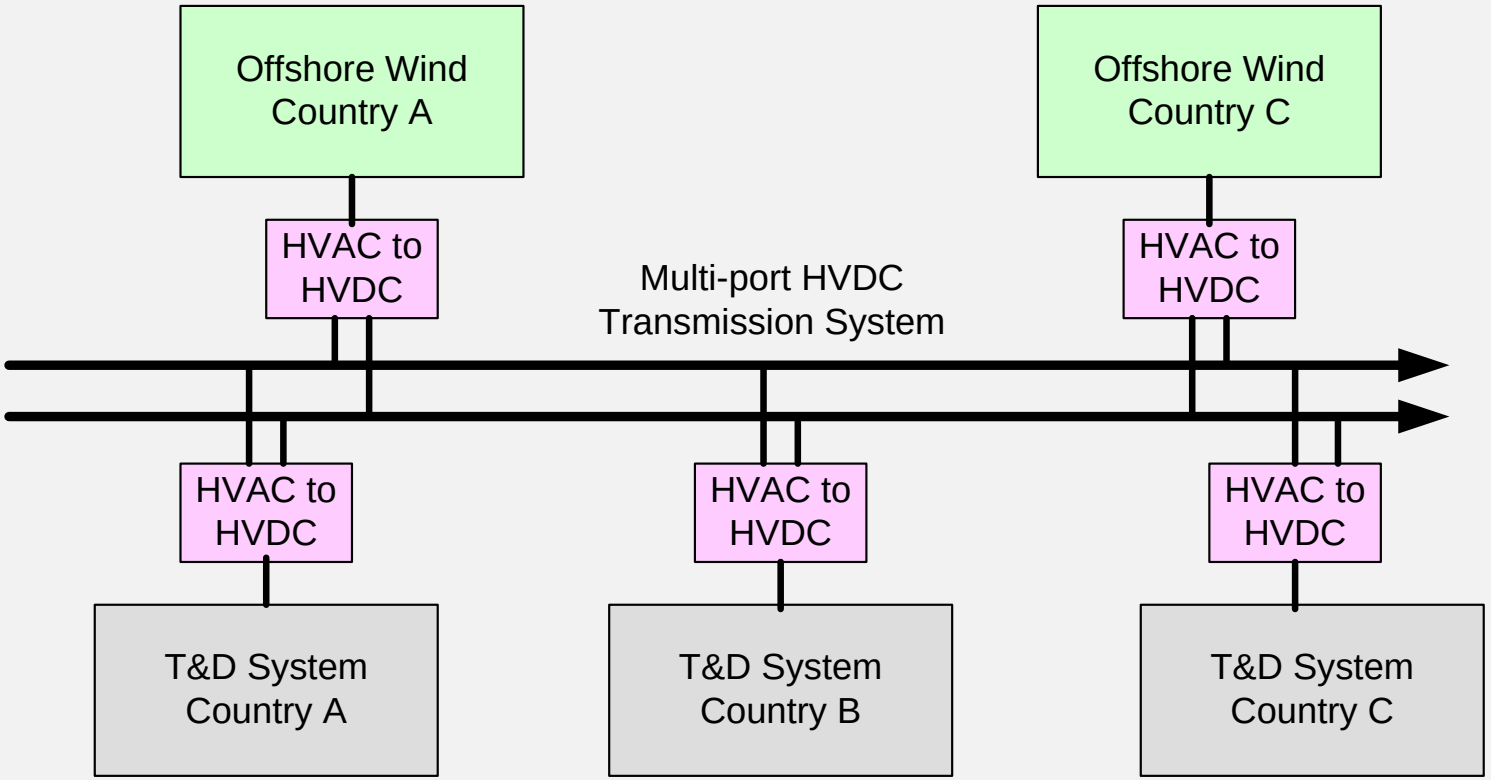




- Cost of construction
  - …pace, transportation,…
  - …tion
  - …ne,…
  - …pact
  - …impact, resources,…



Multiport HVDC Networks



A Simplified Multiport HVDC system

Multiport HVDC Networks

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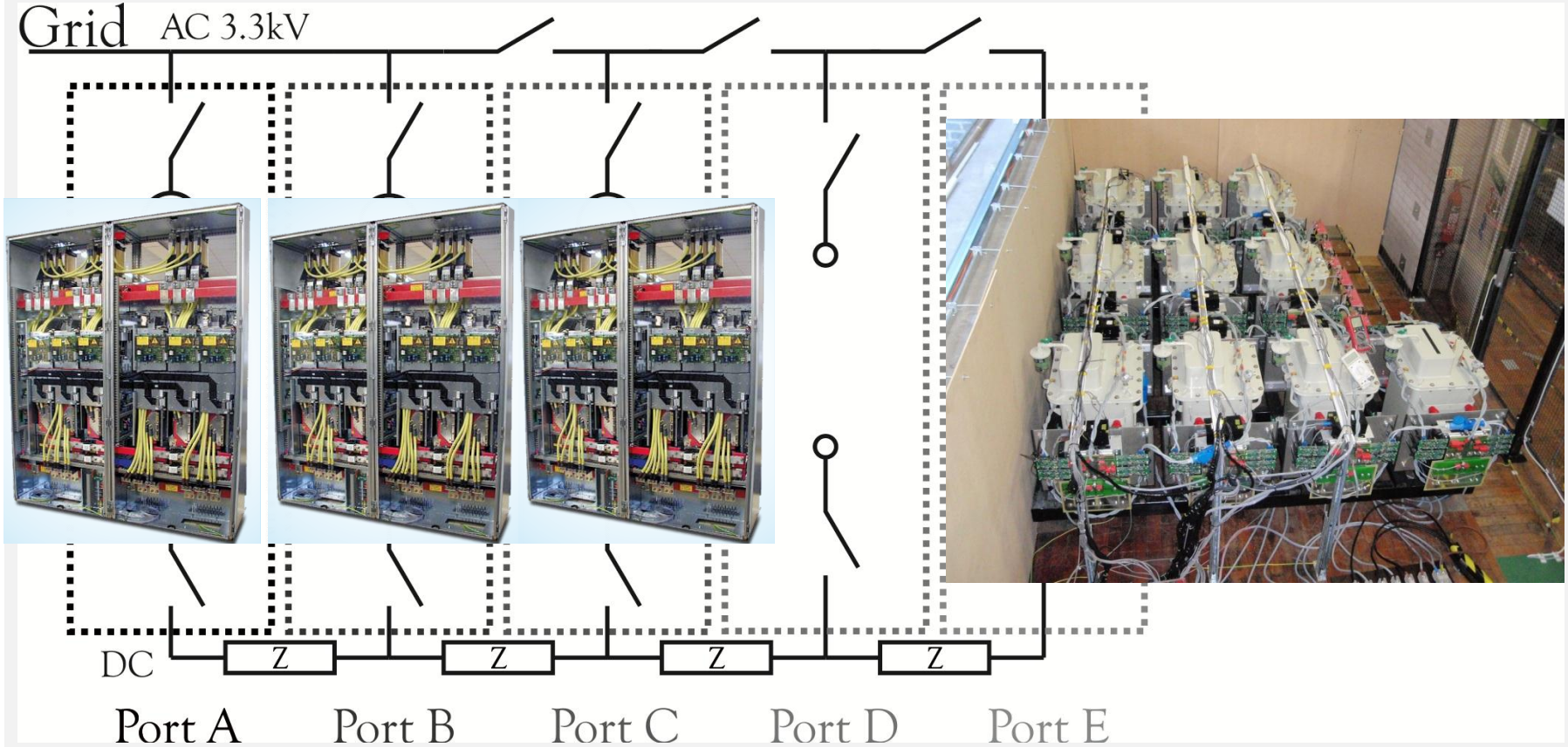
Multiport HVDC Test Facility at University of Nottingham



3.3kV AC, 5kV DC, 5MW Circulating Power
Research on energy management, protection, power electronic converters

HVDC Transmission

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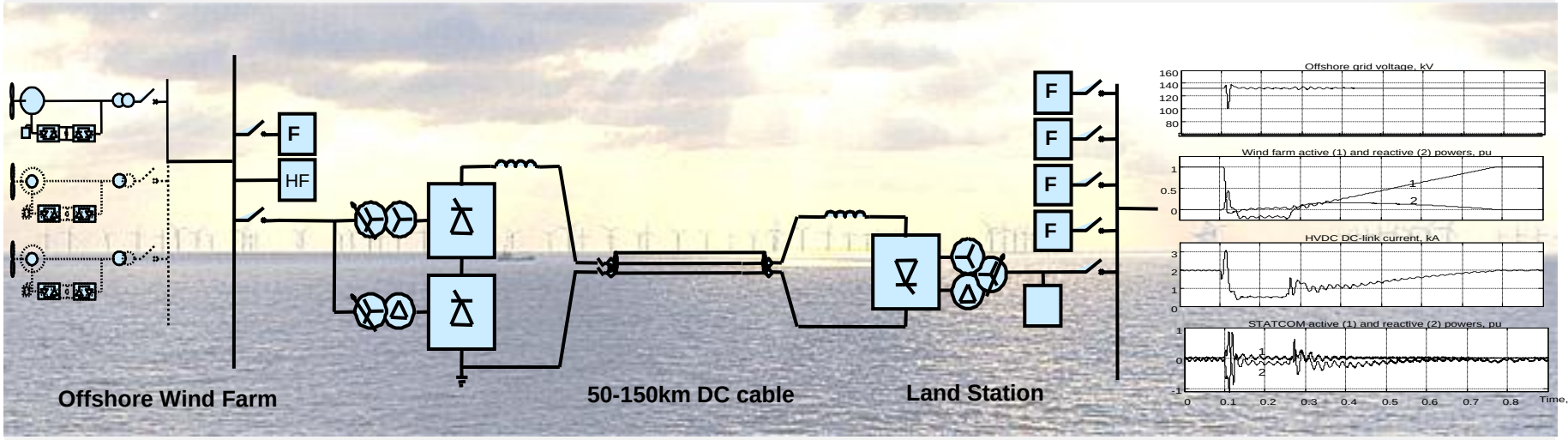
- UK investing ≈10GW of offshore wind capacity with HVDC links to shore
  - STATCOM-less systems, grid control, ride through and protection
  - rugged, cheap, proven, but traditionally large foot print

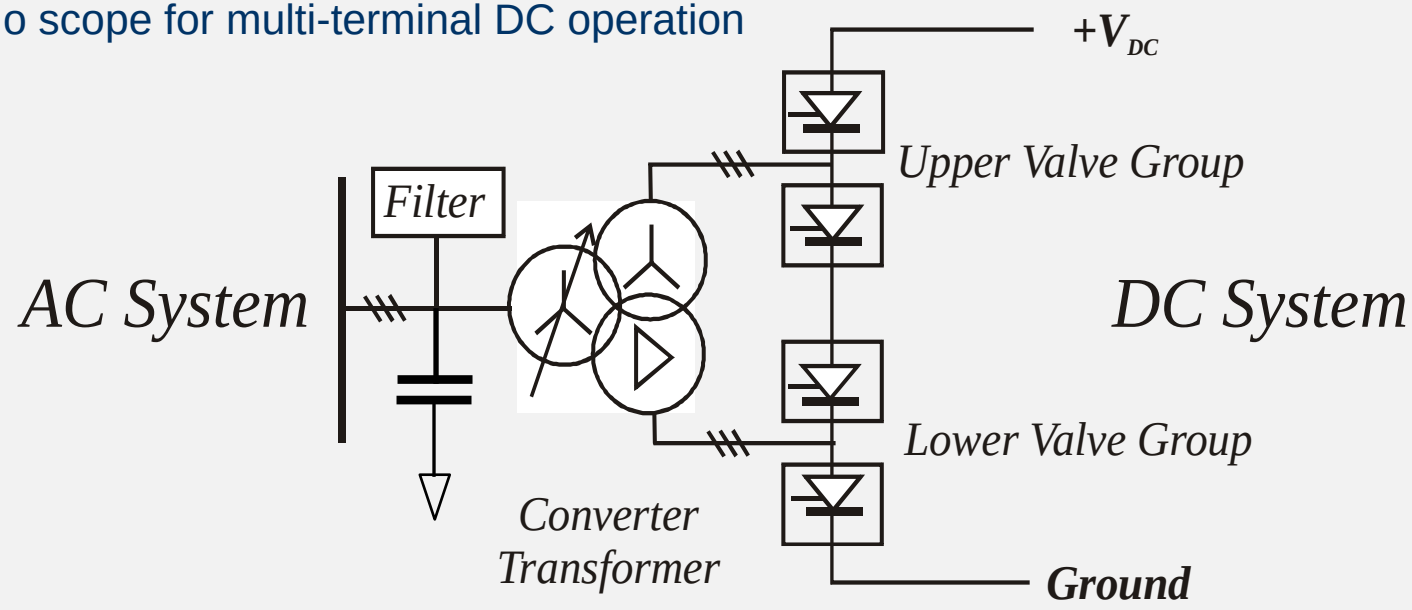
- Voltage Source IGBT Converters (VSC - HVDC Plus ≈500MW)
  - full controllability, small foot print, black start
  - VSC HVDC topologies for high efficiencies, fault performance



HVDC
Converter Topologies

Conventional HVDC Transmission

- Tried and tested technology (50 year history)
- State of the art ±132kV, 6400MW, 2000km
- Problems:
  - Converter station footprint (filters approx 50%)
  - Inability to work on “dead” networks - voltage needed for commutation of thyristors
  - Limited scope for reactive power control
  - Power reversal requires DC voltage reversal - Limits usage to certain cable types
  - No scope for multi-terminal DC operation



Based on line commutated converter (LCC) thyristor technology

Voltage Source Converter (VSC)
HVDC transmission

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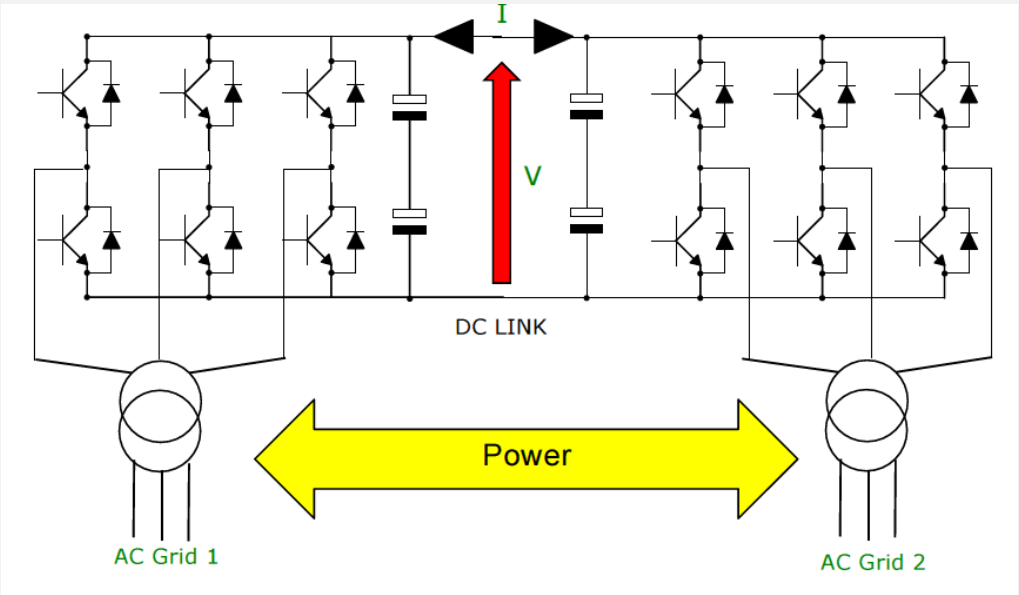
- Voltage source converter HVDC is growing rapidly (±800kV 10GW)
- Many advantages over conventional HVDC eg:
  - "Black start" – can feed a dead network
  - Active and reactive power control
  - Much smaller filters/no compensation (station footprint much smaller)
  - "Constant" voltage DC link ⇒ multi-terminal applications
  - No voltage reversal for power reversal
- Some key problems for VSC converters
  - Efficiency (*switching converter losses*)
  - Operation with faulted AC or DC side
  - Scalability (*modularity)*



Voltage Source Converter (VSC)
HVDC transmission

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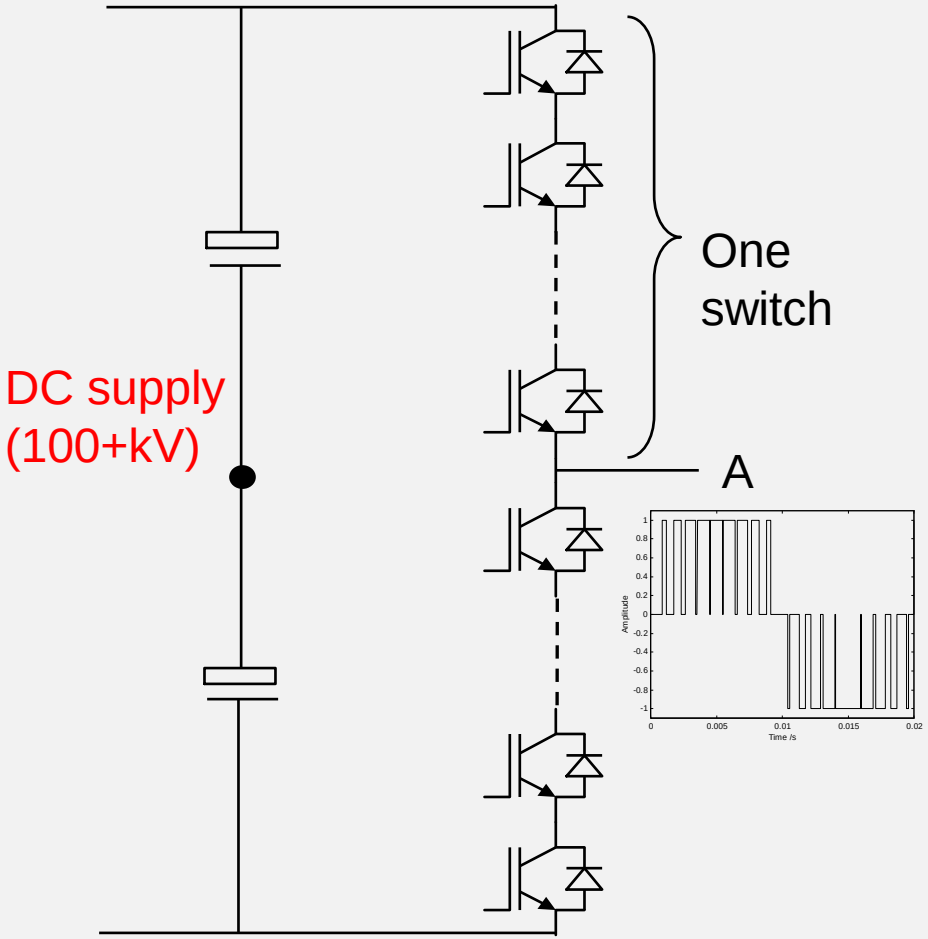
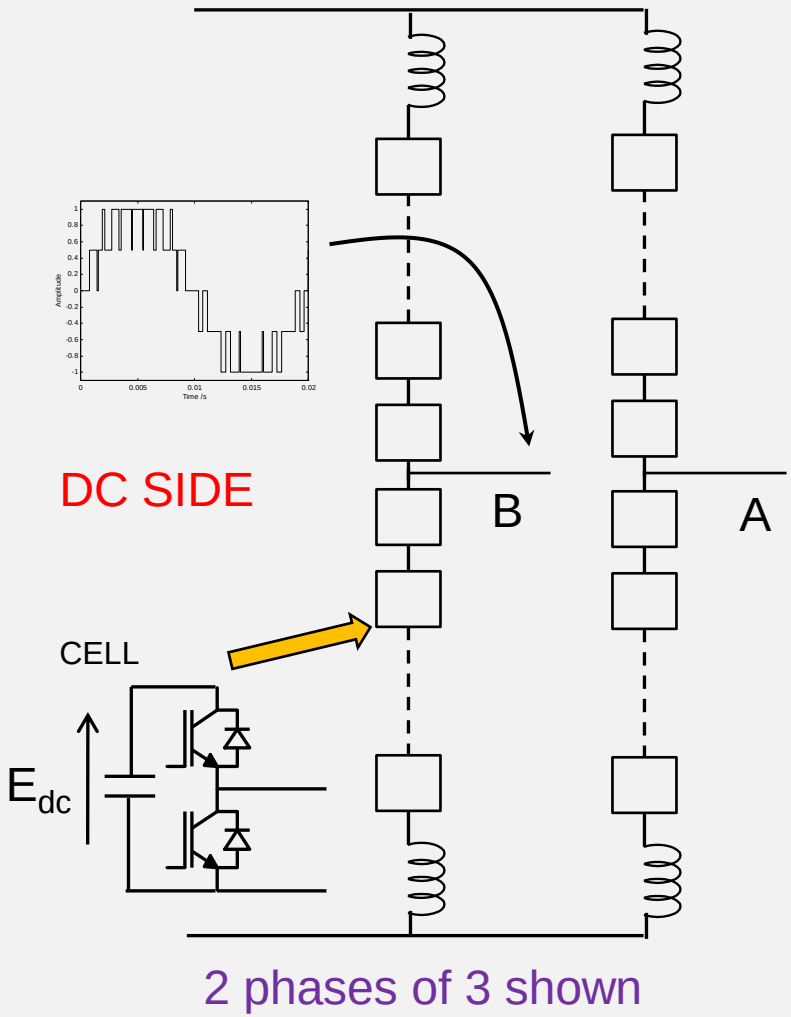
Two-level inverter based on series connected devices



One phase of 3 shown

- Simple concept
- Requires series devices
- 2-level operation – needs relatively high PWM frequency
- High switching losses (total losses 1.7% per station)
- 2-level PWM generates significant harmonics - filtering

Modular-Multilevel-Converter (M^2LC)



- Concept more complex
- Switching of cells controls BOTH the DC side and AC side voltage
- No bulk DC capacitor
- No need for series devices
- Multi-level operation – low switching frequency + good harmonic performance
- Low switching losses (typical total losses 1% per station)
- Twice the number of devices required compared to 2-level approach
- Large number of capacitors of significant size
- Voltage on individual capacitors must be controlled

Modular-Multilevel-Converter (M^2LC)

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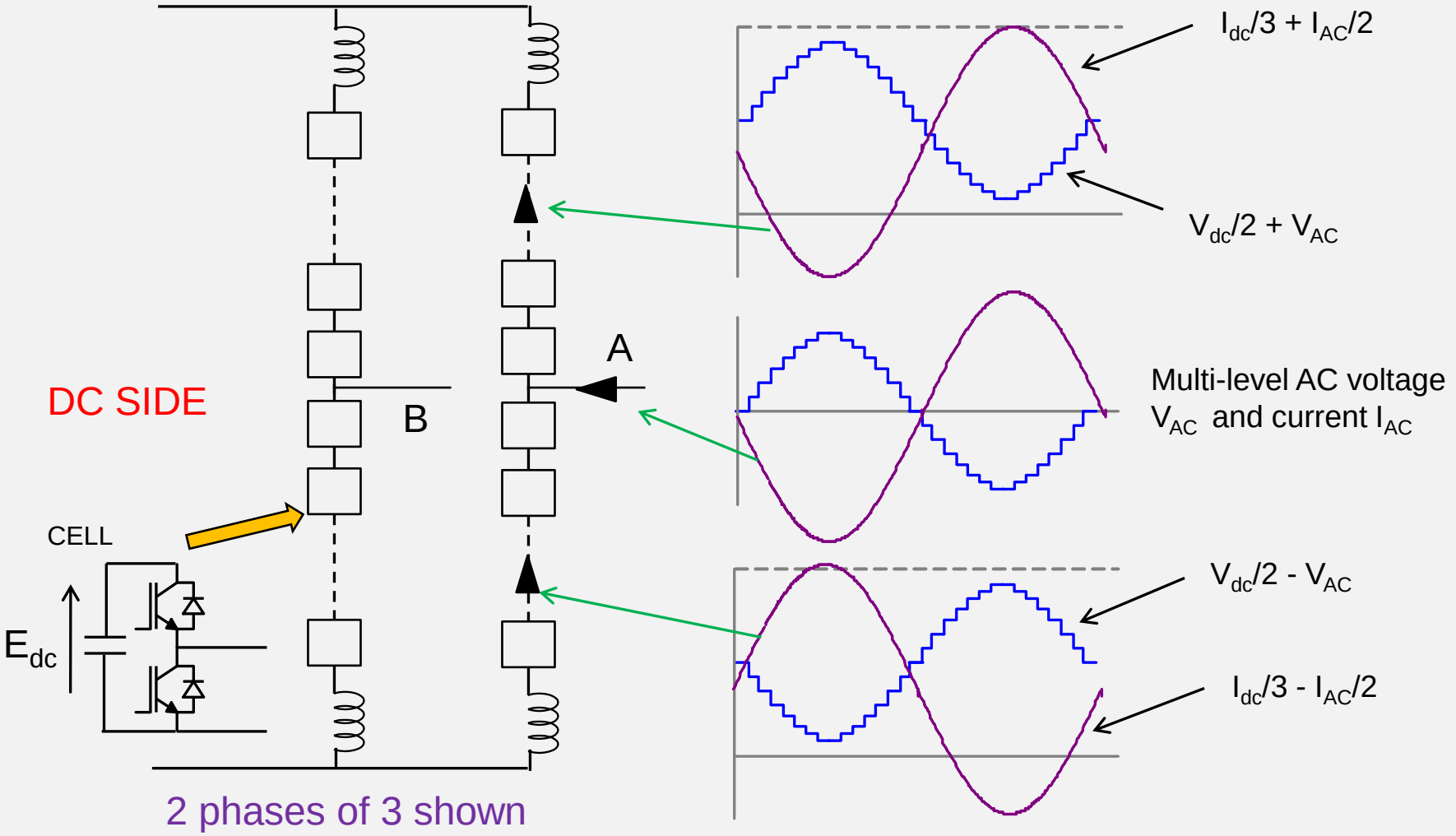


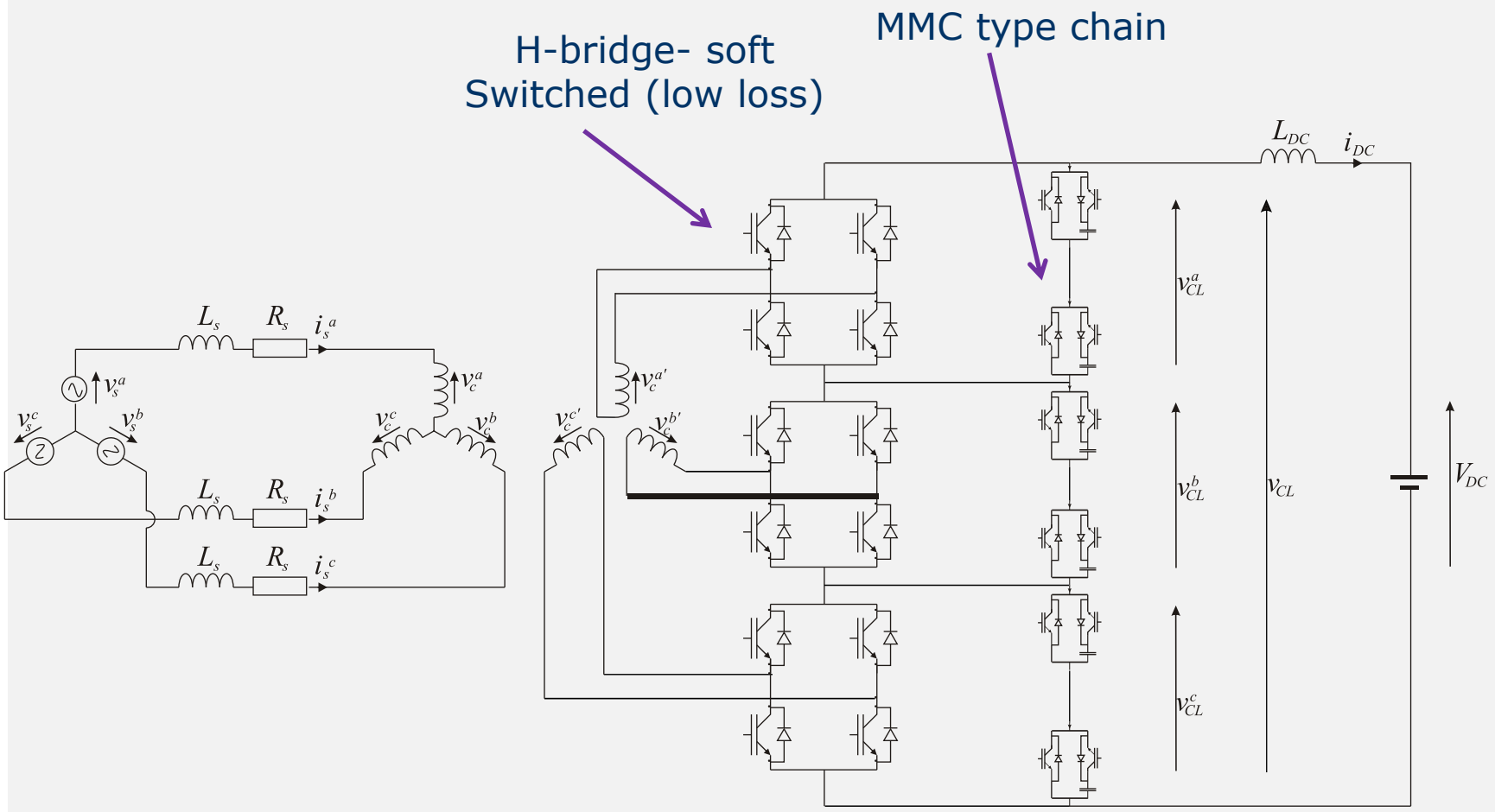
Hybrid Topologies

- Combination of:
  - Multi-level “wave shaping”
    - Series bridges
    - “Modest” switching frequency
    - Fractional rating ⇒ low loss
  - Series device “wave steering”
    - Zero voltage switching
    - Low loss
- Combination gives:
  - High waveform fidelity
  - Low loss
  - Low device count
    - Semiconductors
    - Capacitors

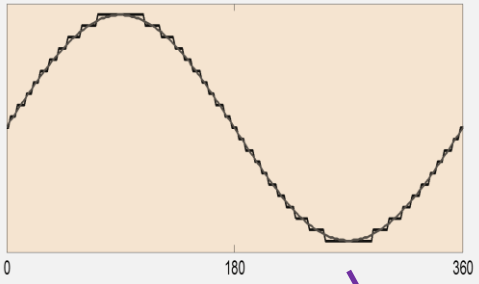
Scale demonstrator design

- 20MW, 20kV DC, 11kV AC
- 1200A, 3300kV IGBTs
- 1.5kV cell voltage

Parallel Hybrid Topology

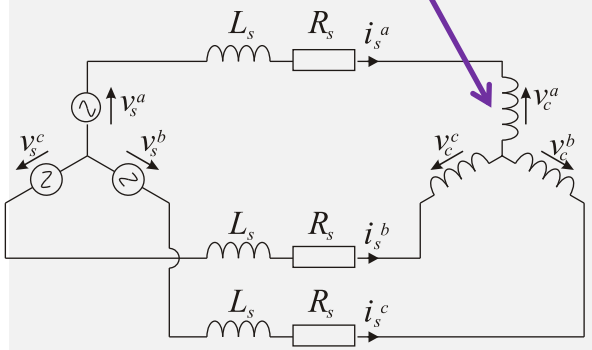


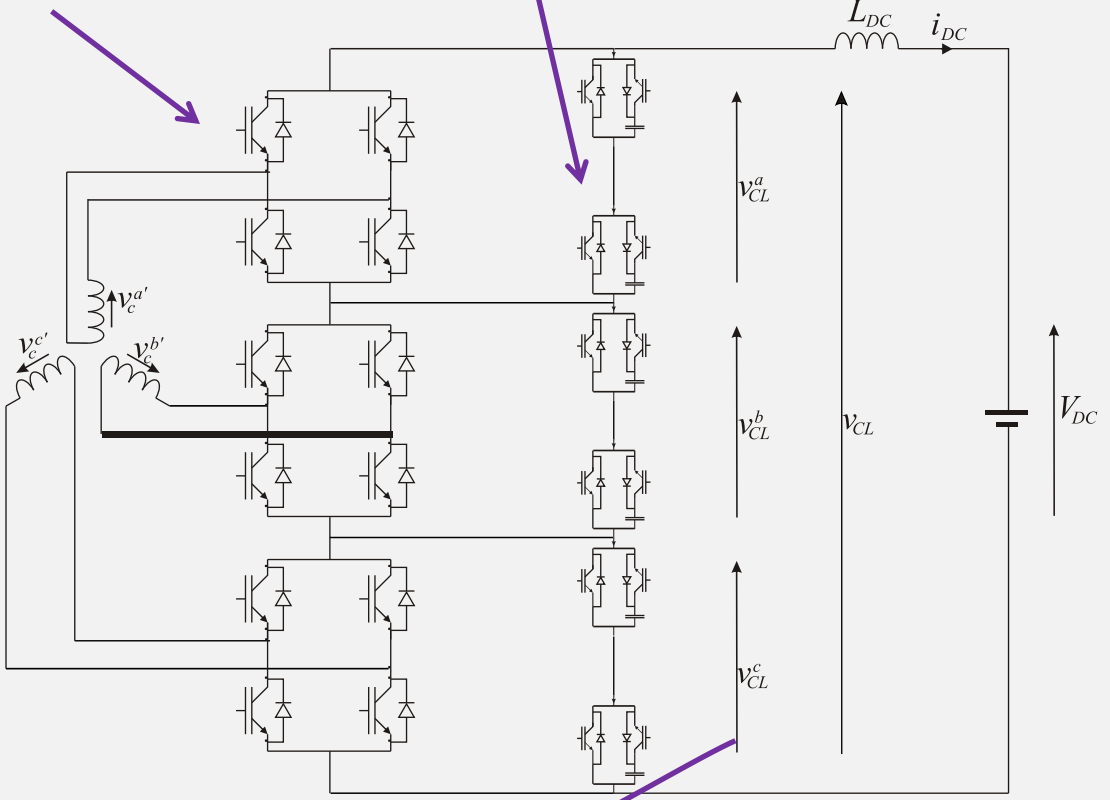
Parallel Hybrid Topology

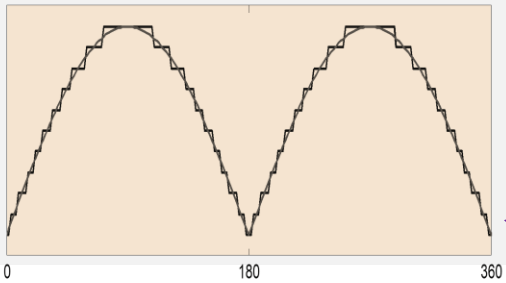


H-bridge- soft Switched (low loss)

MMC type chain







Parallel Hybrid Topology

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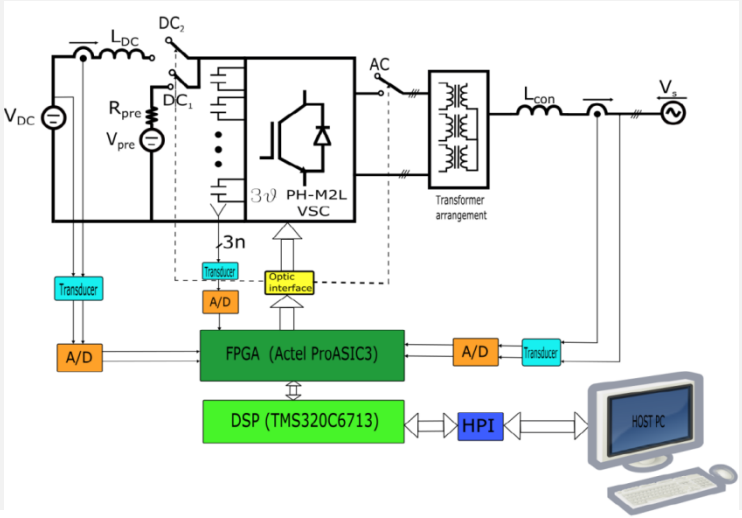
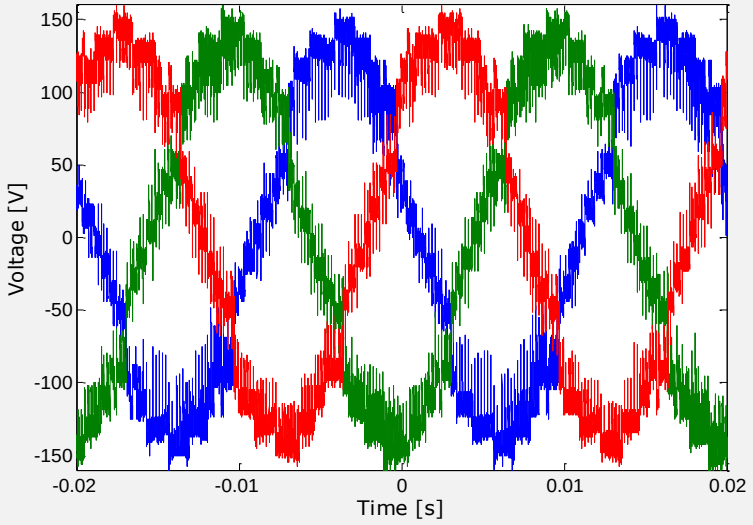
- Topology has a very low component count compared to many alternatives
- Chain-Link converters perform wave shaping function
  - Converters outside of main power path => low switching losses
  - Mean Chain-link current typically <20% of DC current
- H-Bridge converters are zero voltage soft switched
  - Device switching frequency = fundamental frequency
- Research Topics
  - Theoretical work on energy control (unbalanced supply etc)
  - Closed loop control and Energy management





Line-Line voltages at the converter terminals

Parallel Hybrid Topology

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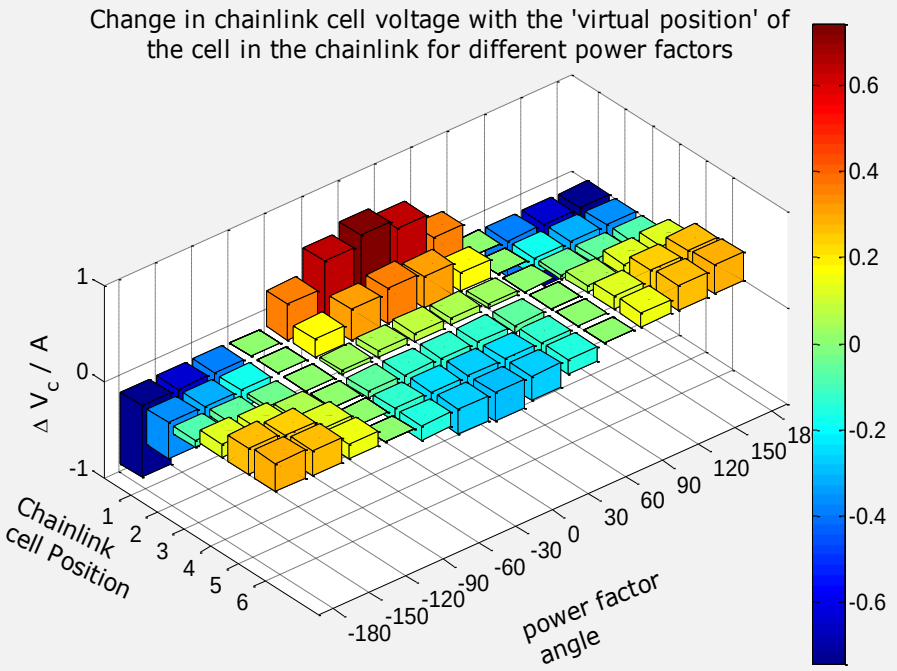
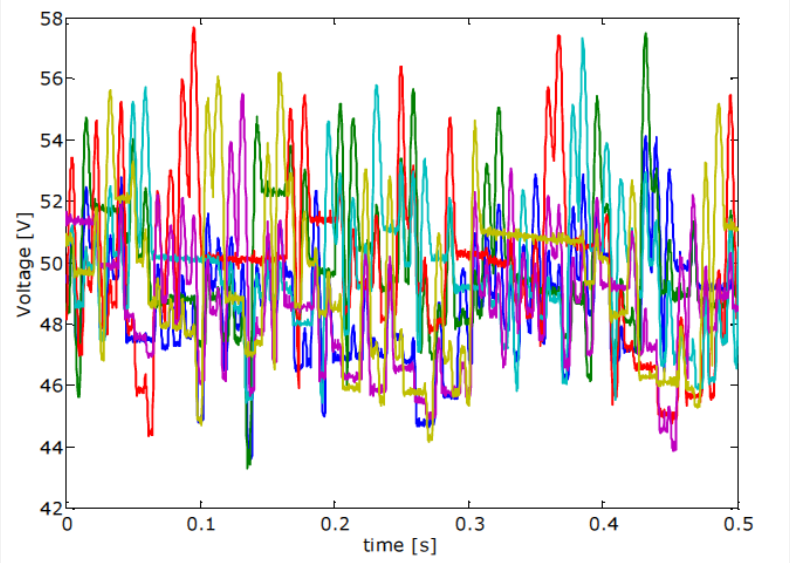
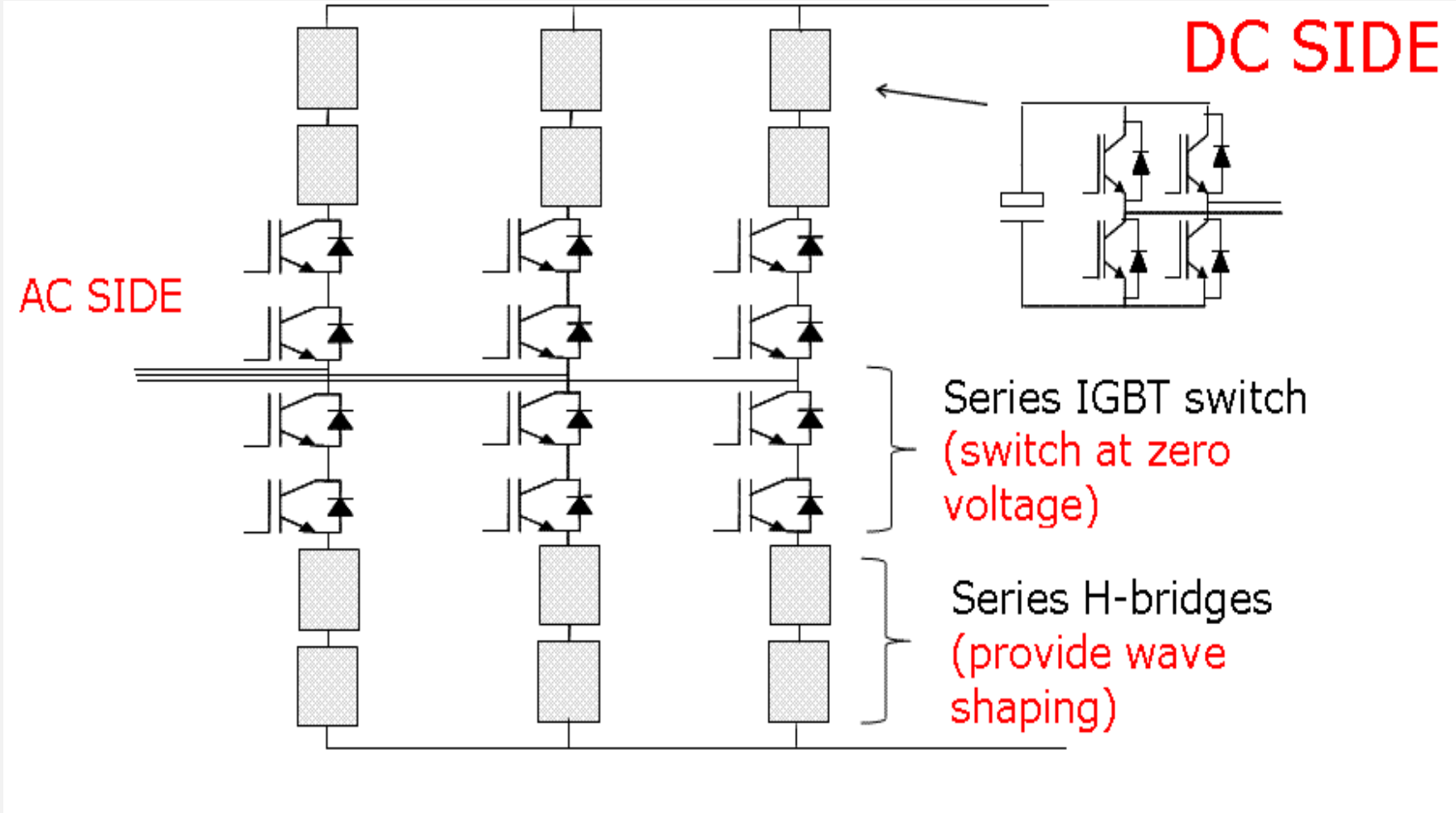
- Chain-link cell capacitors have a tendency to charge or discharge
  - Have to control the voltage of the individual converter chain-link capacitors
- Balancing can be achieved with a sorting algorithm based on the characteristics of the chain-link cells in a given chain-link position





Capacitor Voltage Control
one phase with set point = 50V

Series Hybrid Topology



Series Hybrid Topology - AAC

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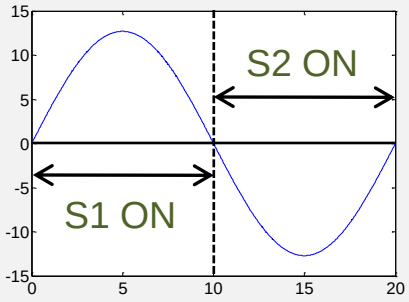
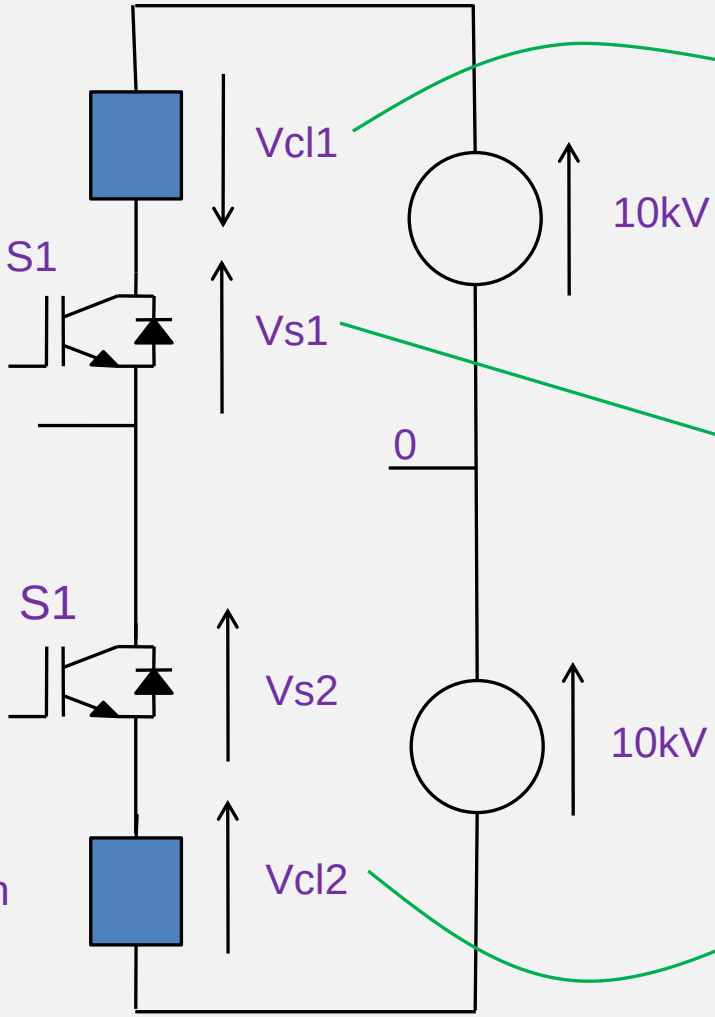
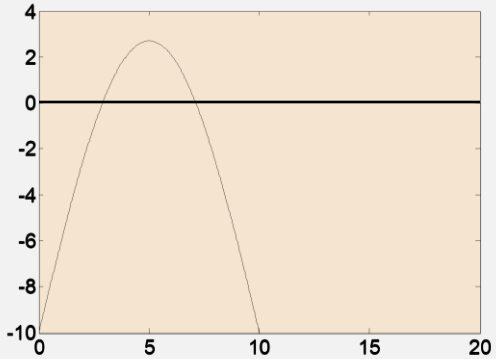
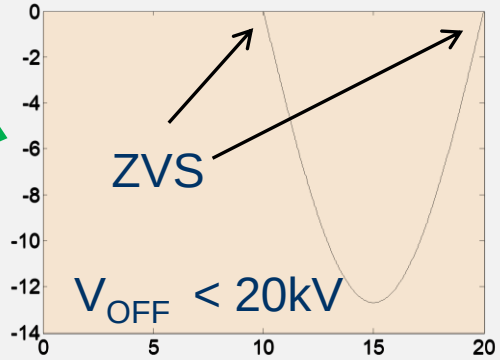
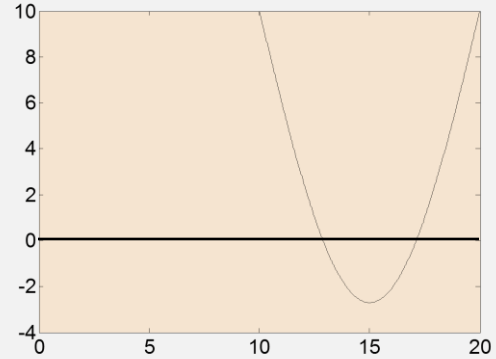










Condition for zero energy exchange with chain-links

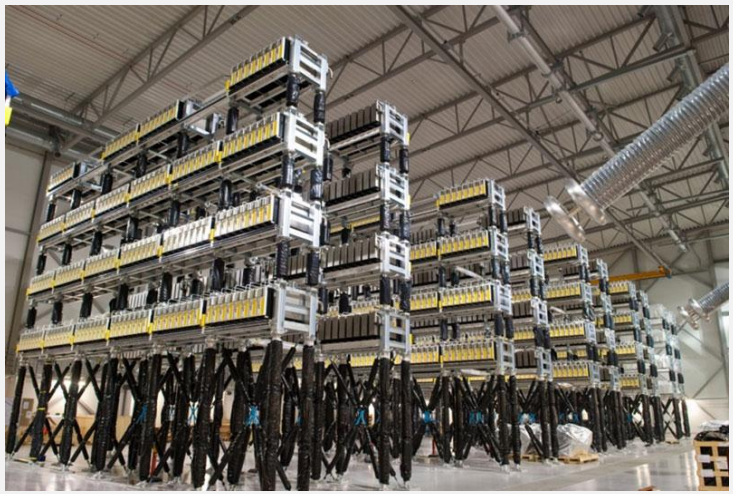
$V_{AC}(peak) = 2E_{DC}/\pi$

Series Hybrid Topology - AAC

ADVANTAGES

- Series IGBT switches commutate at near zero voltage
  - Reduce switching losses
  - Improves converter efficiency

- Series H-bridges can support the AC voltage when there is a DC side fault
  - Actively control AC side current to zero
  - No need to interrupt fault current with AC side breaker
  - Actively control AC current to be reactive
  - Gives option of STATCOM performance during DC side fault



Topology Comparisons

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	2-level converter	Half-link M^2LC	Full-link M^2MC	Series hybrid	Parallel hybrid
Total Semiconductor count (pu)	1	2	4	2.5	1.5
Total submodule DC capacitor rating (pu)	0	1	1	~0.5	<0.25
Losses	★☆☆☆☆	★★★★☆	★★☆☆☆	★★★☆☆	★★★★☆
AC Harmonic performance	★★★☆☆	★★★★★	★★★★★	★★★★★	★★★★★
Hard-switched IGBT valve needed?	✓	✗	✗	✗	✗
Ability to suppress DC faults?	✗	✗	✓	✓	✗

Summary

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- Power Converters will be an essential part of the future Electrical Energy Grid
- Renewable Energy Sources are not directly compatible with the grid
  - Requirement for Power Conversion for all power source connections
- Challenges for Power Converter deployment in the Electricity Grid
  - Cost [both purchase cost and cost of losses]
  - Reliability/availability
  - Current regulations and legacy equipment
- Many other topologies exist for AC/AC and AC/HVDC
  - Newton-Picarte project between Universities of Nottingham/Talca/Concepcion will look at some alternatives
  - Kick Off meeting was held in Talca a couple of weeks ago!

2015 Season eSuperBike

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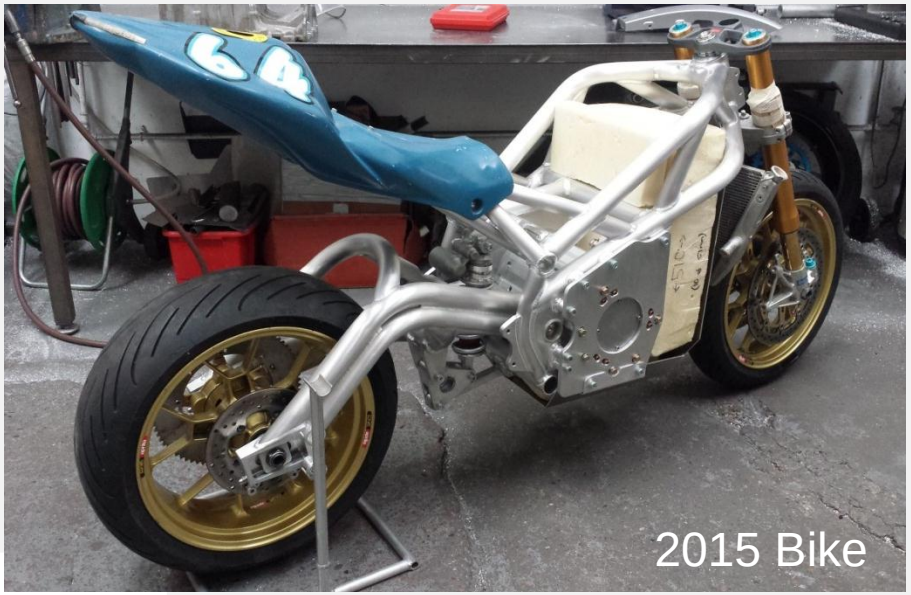
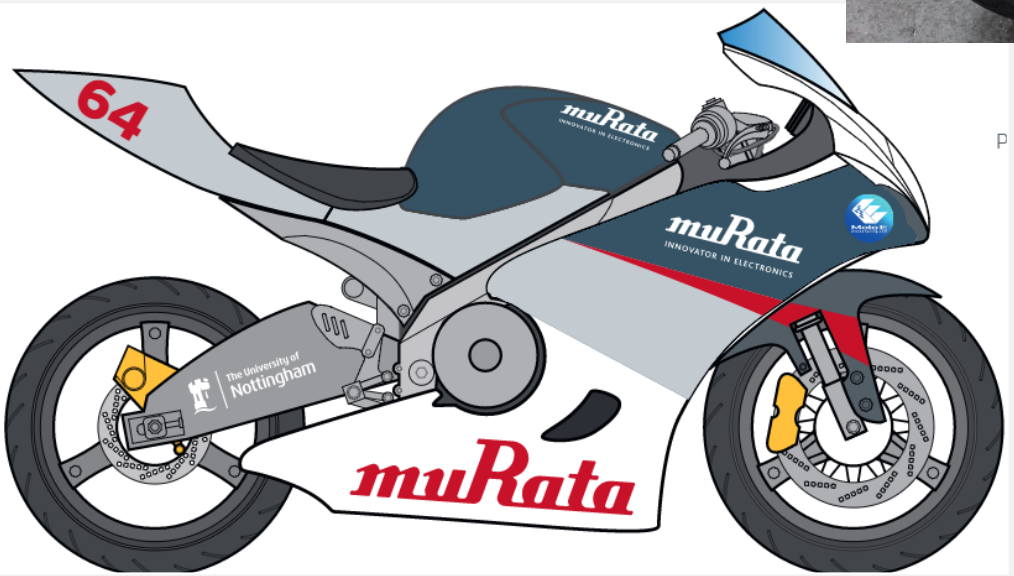
- 2015 electric bike will have 3 x Torque of the 2014 bike
- Custom designed and built frame
- Motor and Controller built by the team in Nottingham
- TT on Isle of Man in June 2015!
- > 280km/hr



2015 Bike




2014 Bike