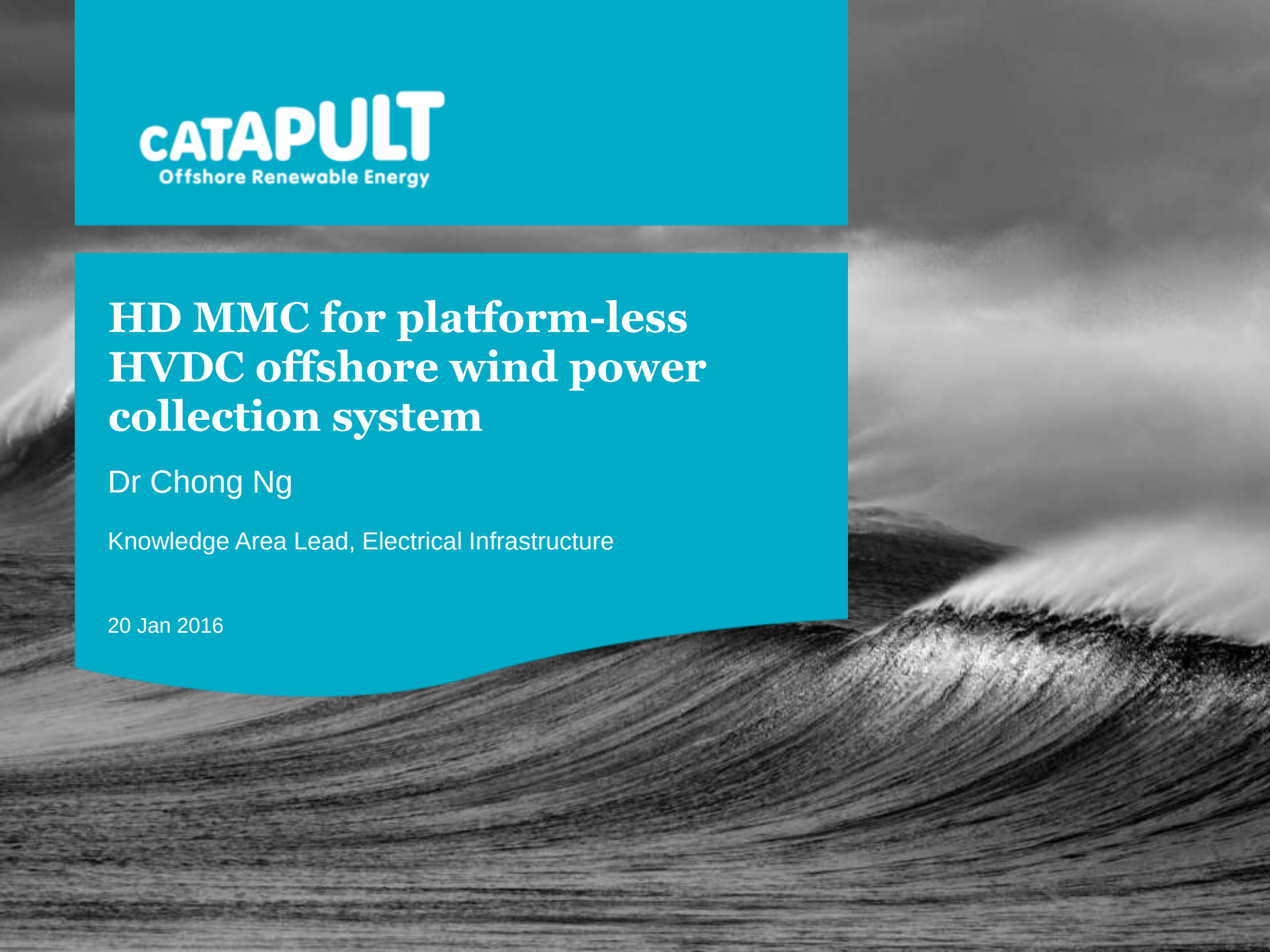

CATAPULT
Offshore Renewable Energy

HD MMC for platform-less HVDC offshore wind power collection system

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- Platform-less Offshore HVDC System
  - Research History
  - Current Status
- HD MMC
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  - HD Proposed Solution

Catapults: A long-term vision for innovation & growth

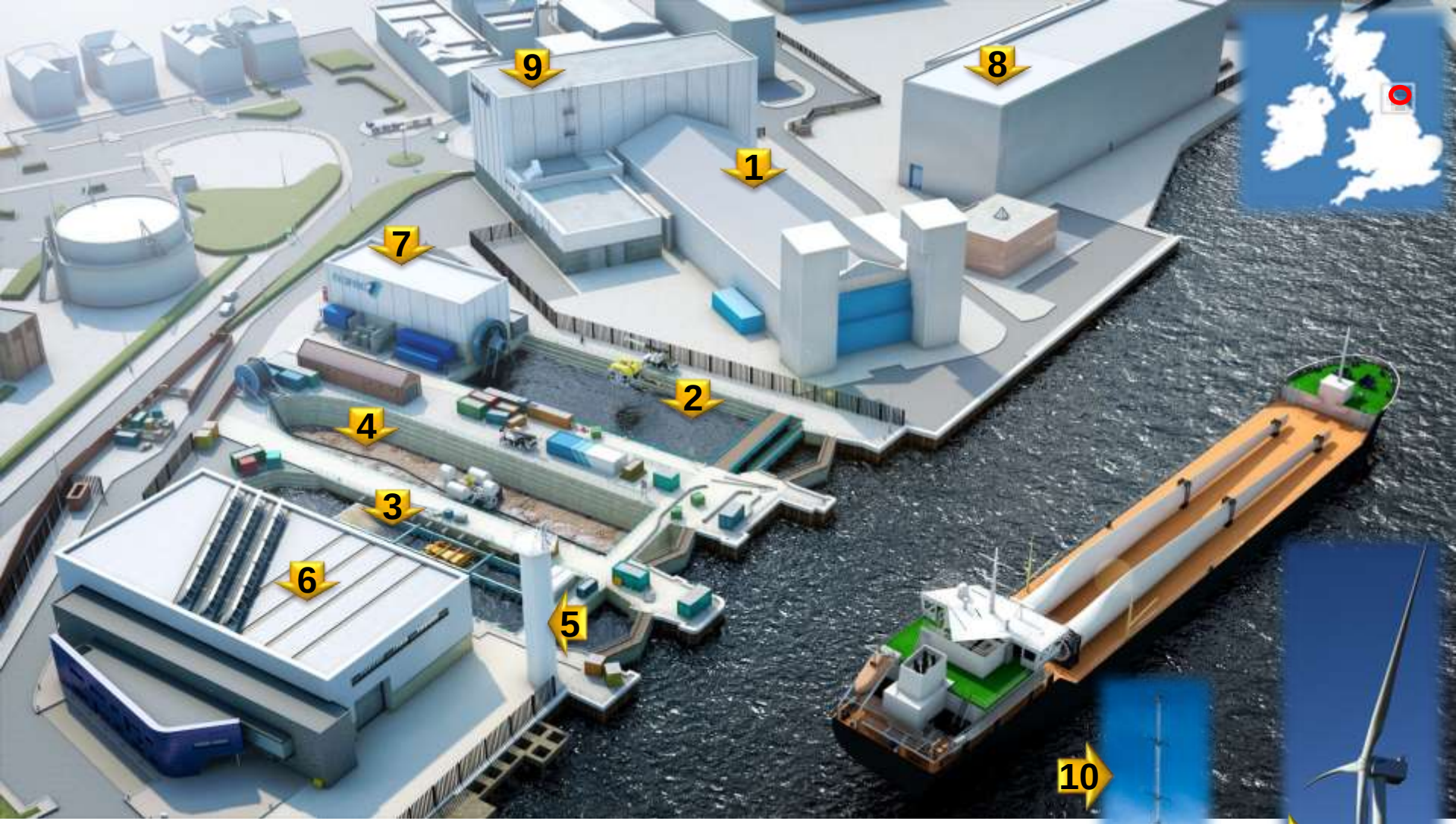
Cell Therapy Catapult	Connected Digital Economy Catapult	Future Cities Catapult	High Value Manufacturing Catapult	Offshore Renewable Energy Catapult	Satellite Applications Catapult	Transport Systems Catapult

- Established and overseen by the Technology Strategy Board
- Bridging the gap between business, academia, research and government to create new products and services
- Open up global opportunities and generate sustained economic growth for the future
- Delivering the ‘know-how’ economy

7
Catapults

£1.4bn
private and public sector investment

Offshore Renewable Energy (ORE) Catapult



A Controlled and Independent Development Platform

Existing

1. 50m blade test
2. Still water tank
3. Wave flume
4. Simulated seabed
5. Wind turbine training tower
6. Electrical and materials laboratories

New

7. 3MW tidal turbine drive train
8. 100m Blade Test Facility
9. Wind Turbine Nacelle Test Facility-2013
10. Offshore anemometry hub
11. 7MW Wind Turbine

Electrical (HV & LV) Test Lab – Brief

- HV development laboratories – 600kVac, 1MVdc, 8kA, Rain drop simulator, Material lab
- Live environmental chamber – HV and current into chamber
- Flexible three phase LV network – generators & converters array (up to 100kW)
- Grid conformance testing – G59 test equipment in the facility
- 11kV 50Hz network available
- Vibration test rig – loads up to 500kg for endurance and accelerated ageing programmes

Project Example

HD MMC for Platform-less Offshore HVDC System

Project Example

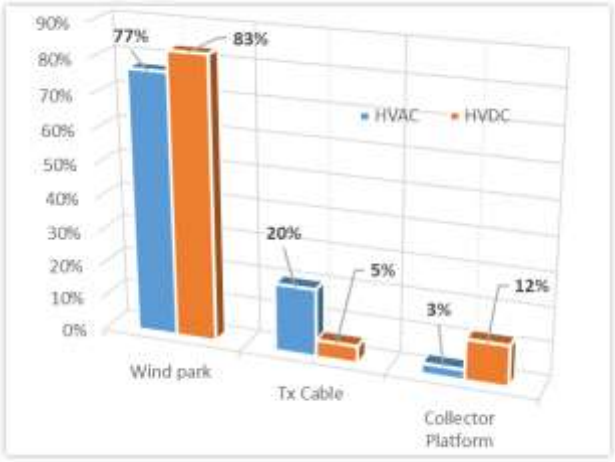
Research History in here

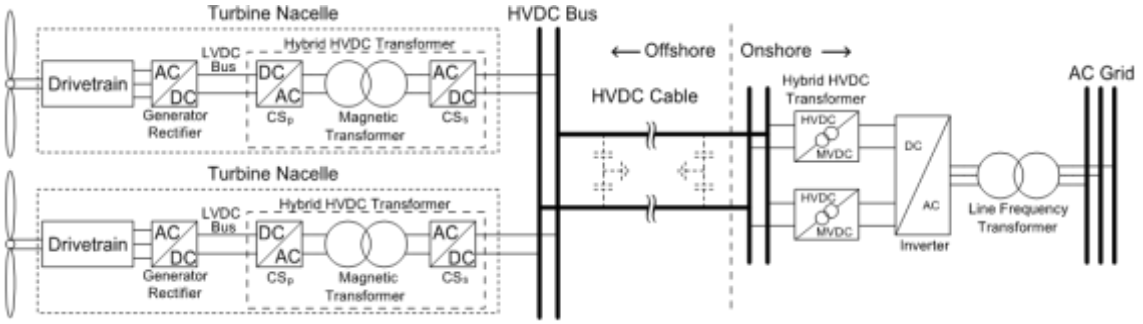
Platform-less Offshore HVDC System

Objective: Develop a dedicated high fault tolerances, flexible and cost effective power collection technology for offshore wind industry

Features:

- HVDC power transmission from the very beginning
  - Reduce losses and components
- Decentralised multi-terminal HVDC system
  - Increase availability – Offers flexibility and redundancy
  - Reduce cost – Removal/minimise offshore substation
- Increase MMC voltage level without additional hardware





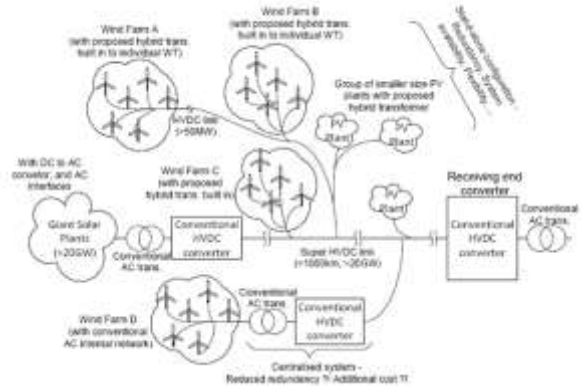
Converter topology analysis

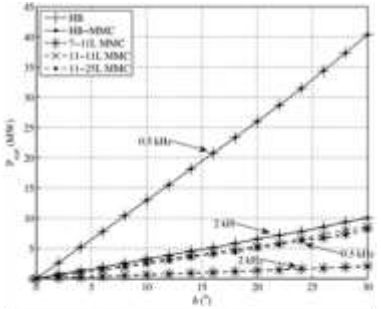
Analysed across frequency range; 100Hz to 2kHz, single phase

Findings:
Transformer core loss ≤ converter loss
Transformer core loss ≤ copper loss

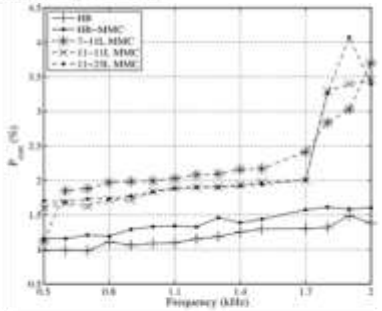
HB-HB configuration:
+ Lower component count
+ Lower converter loss
- Less stable (power control) due to higher voltage gradient
- Higher transformer loss (i.e. 1% higher than MMC)

MMC-MMC configuration:
+ Better control stability (<500Hz)
+ Lower transformer core loss
- Higher component count
- Higher converter loss

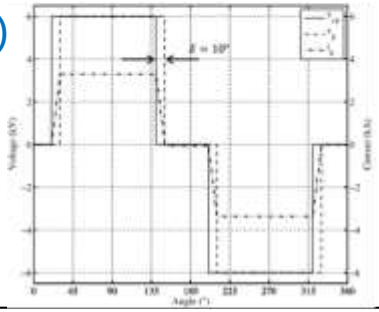


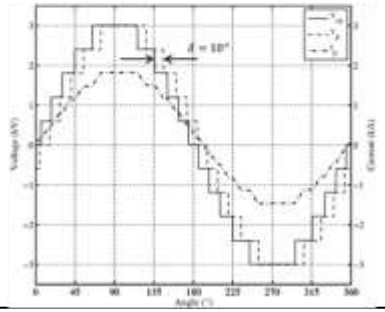


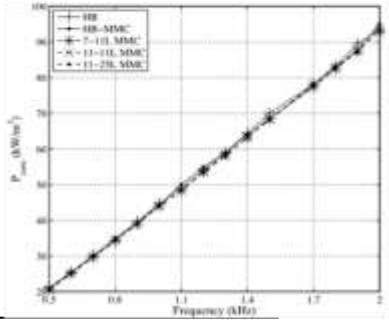
Power output for MMC and HB configurations vs. increasing load angles at 0.5 kHz and 2 kHz.



Converter losses for over the MF range

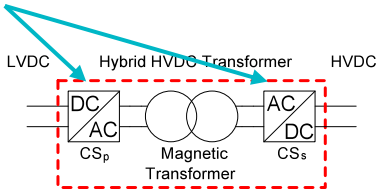


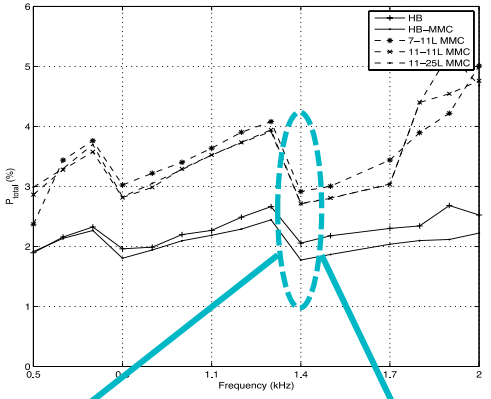


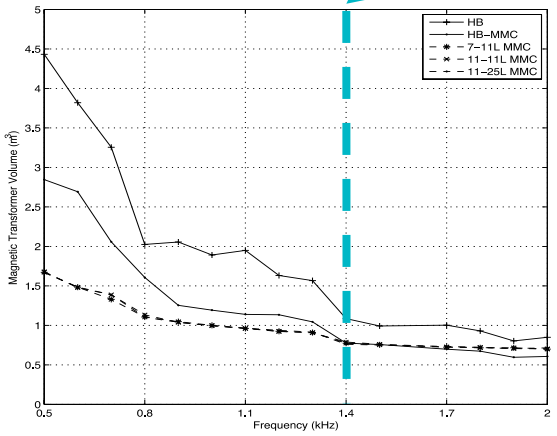


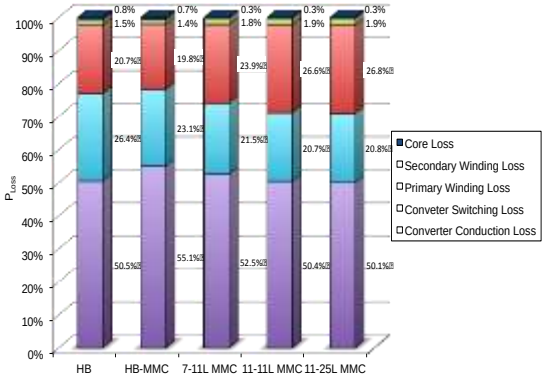
Results

- Different converter configurations modelled in Simulink
  - HB-HB
  - HB-MMC
  - MMC-MMC
- Based on input waveforms, the transformer specifications are optimised and losses calculated
- Repeated for frequencies between 500 – 2,000 Hz
- Optimum configuration found to be HB-MMC at 1.4 kHz
- Majority of losses attributed to converter conduction losses
- This can be decreased by moving to 3-phase



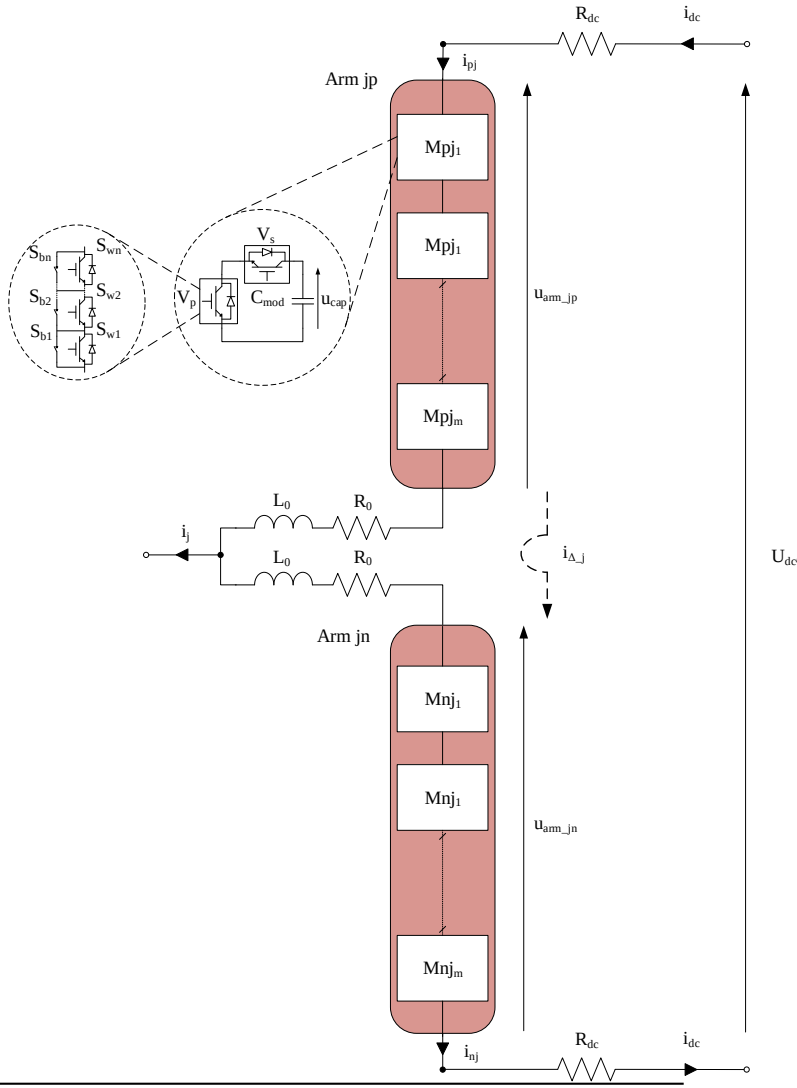






The Modular Multilevel Converter

- Its modular design make it ideal for scaling up.
  - Now used in a variety of applications, including HVDC
- Very attractive for offshore wind
  - Low THD on AC terminal therefore no bulky filters
  - High Efficiency
  - High degree of controllability

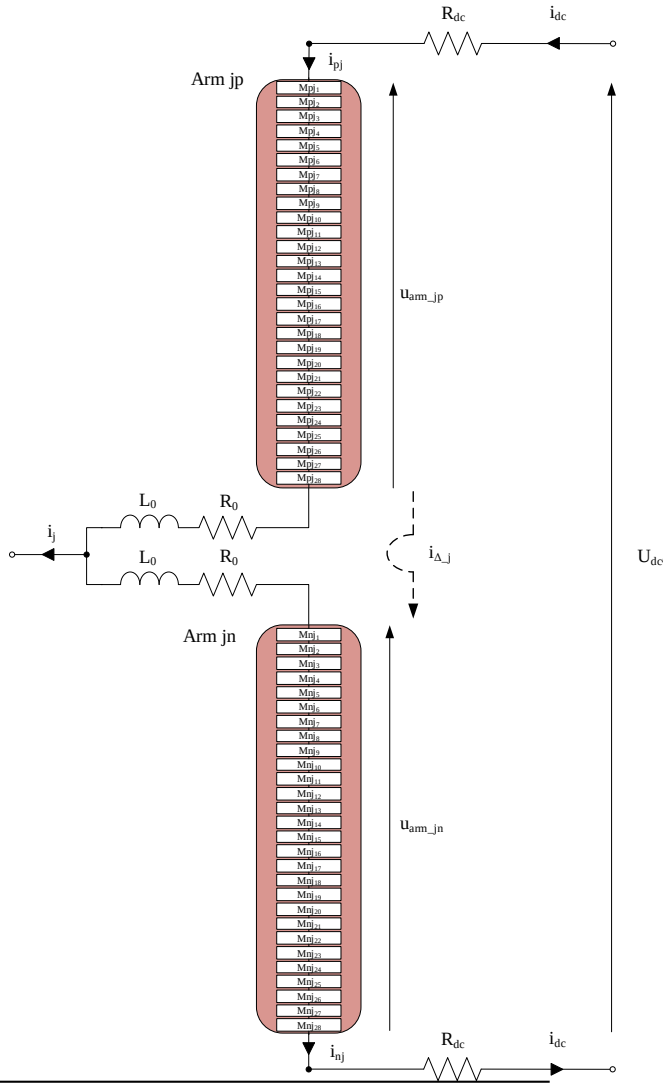


The Modular Multilevel Converter (MMC) Limitations

- Each module can only create 1 AC voltage level L_{conv}:

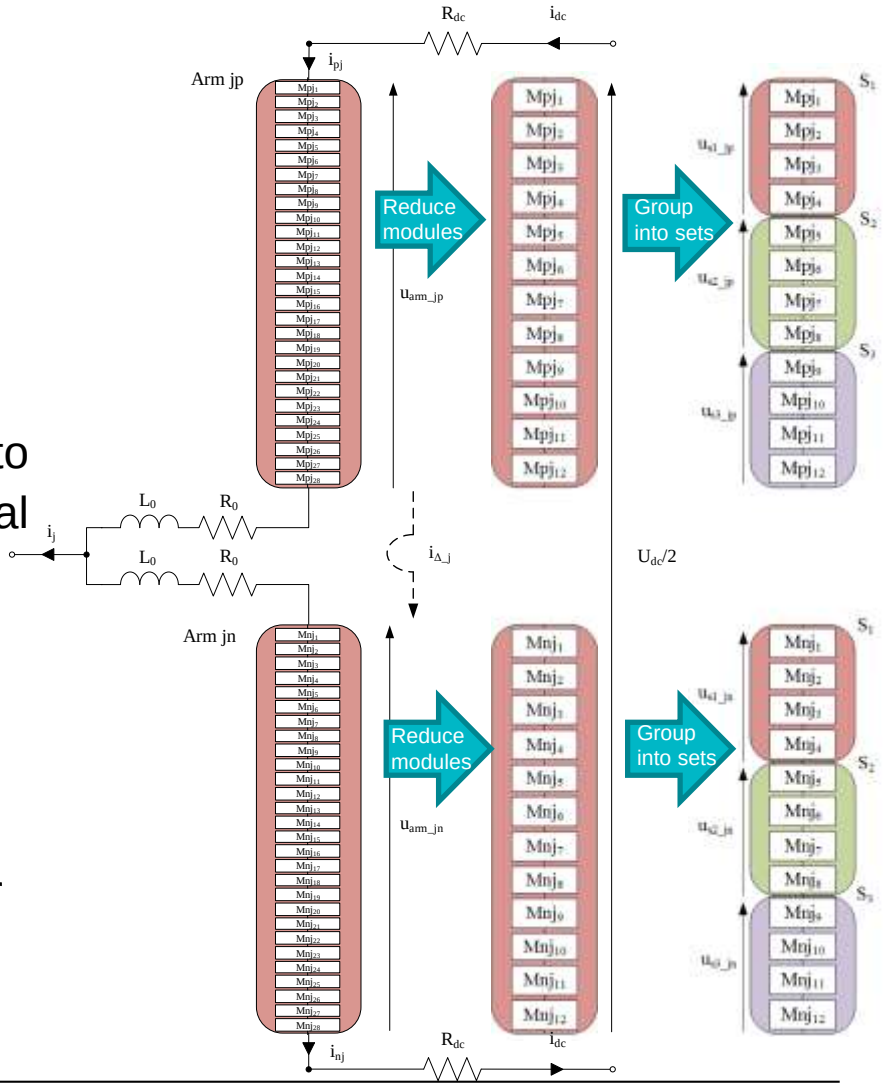
$$L_{conv} = n_{mod} + 1$$

- Therefore many modules required to reduce THD < 3 % (≈ 30)
- Each module requires 2 valves and a large capacitor
    - Capacitor contributes to roughly 50 % of the module volume
- Therefore low THD increases converter losses but crucially converter size and weight
- A LARGE offshore platform required to support it.
- Platform accounts for ≈ 70 % of substation cost therefore significant savings possible by reducing size

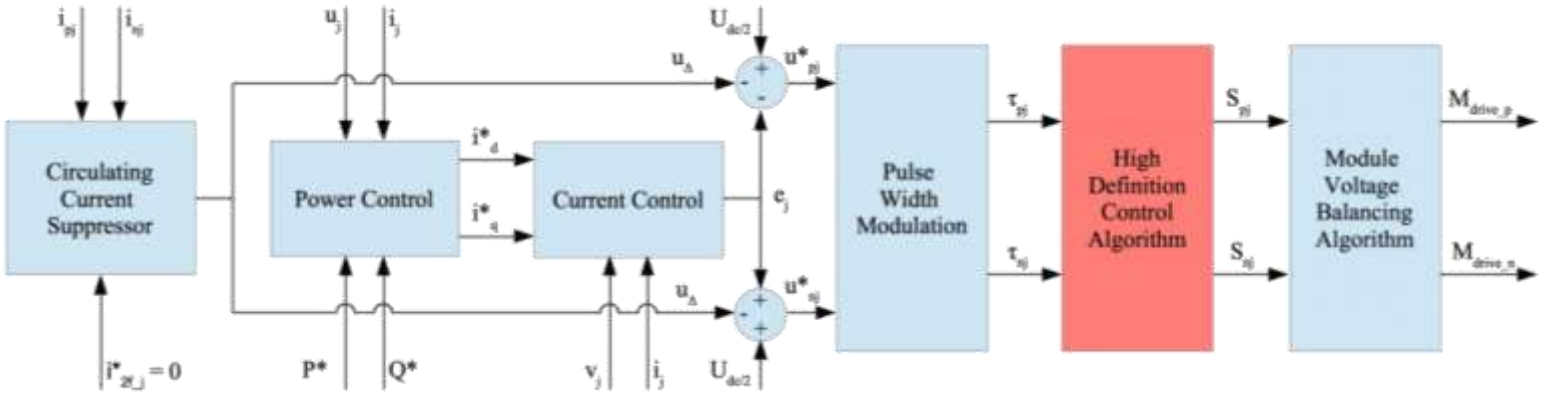


The High Definition Modular Multilevel Converter

- By using the novel HD-MMC control algorithm 1 module corresponds to **multiple AC voltage levels**
- Using the HD-MMC algorithm only **12 modules** are required to create **29 L**
- This is achieved by grouping modules into sets, controlling each to provide additional voltage levels such that L_{HD} is given by:
- Therefore **fewer** capacitors and **fewer** valves
- This results in a more compact converter reducing platform size and cost

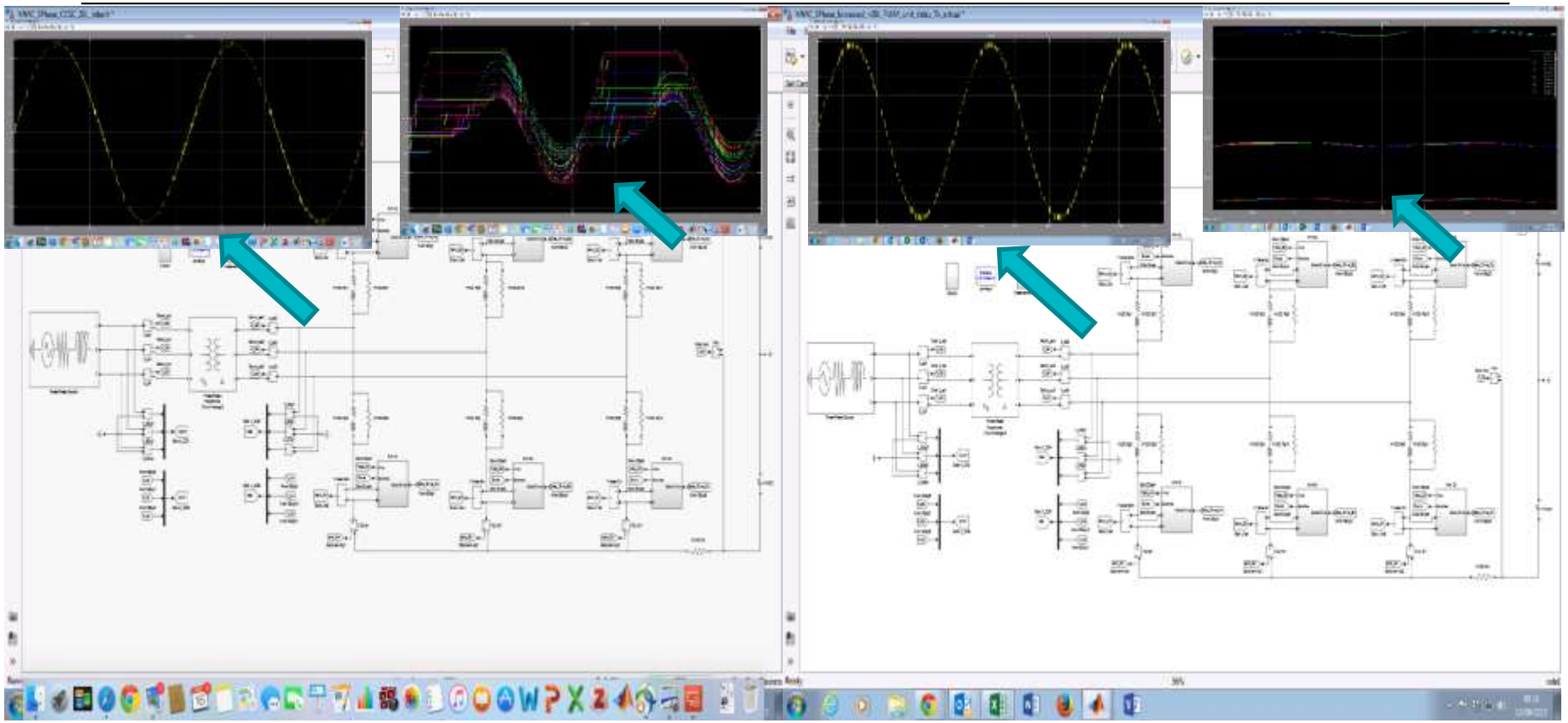


Proposed HD-MMC Control



- Non intrusive, the HD-MMC control algorithm (red) can be inserted as an add on to the standard control methods (blue) of the MMC.
- This simplifies implementation

HD-MMC Simulation Results



- On the left is a standard 28 level MMC and on the right is the HD-MMC concept.
- Capacitor voltages are maintained at set value throughout simulation

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