Research Opportunities for better integration of Offshore wind farms using HVDC links

(The Future of HVDC)

William Ross MEng
Ioannis Antoniou MSC
Research Students
University of Strathclyde

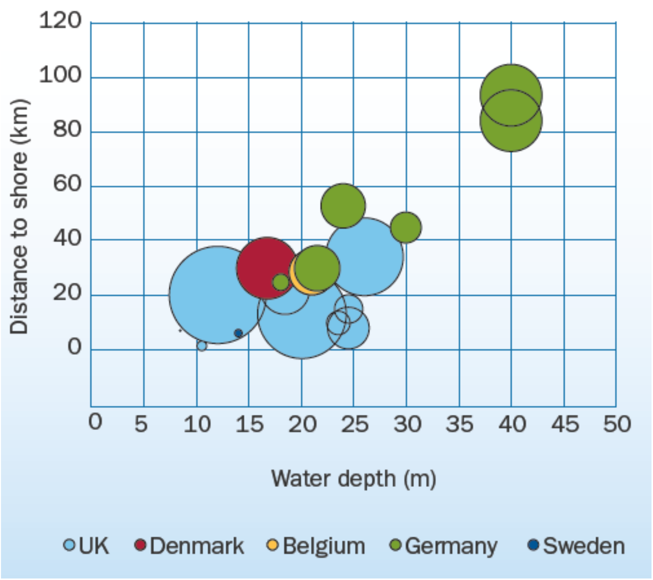
Outline of Presentation

- Annual Report Outcomes
- Where next
- Why HVDC
- Multi Terminal HVDC
- HVDC Converter Technology
- Earlier VSC Technologies
- Modular Multilevel Converters
- Offshore DC Grid Connection
- Protection Requirements
- Issues for further integration
- Conclusions

Some Annual Report Outcomes

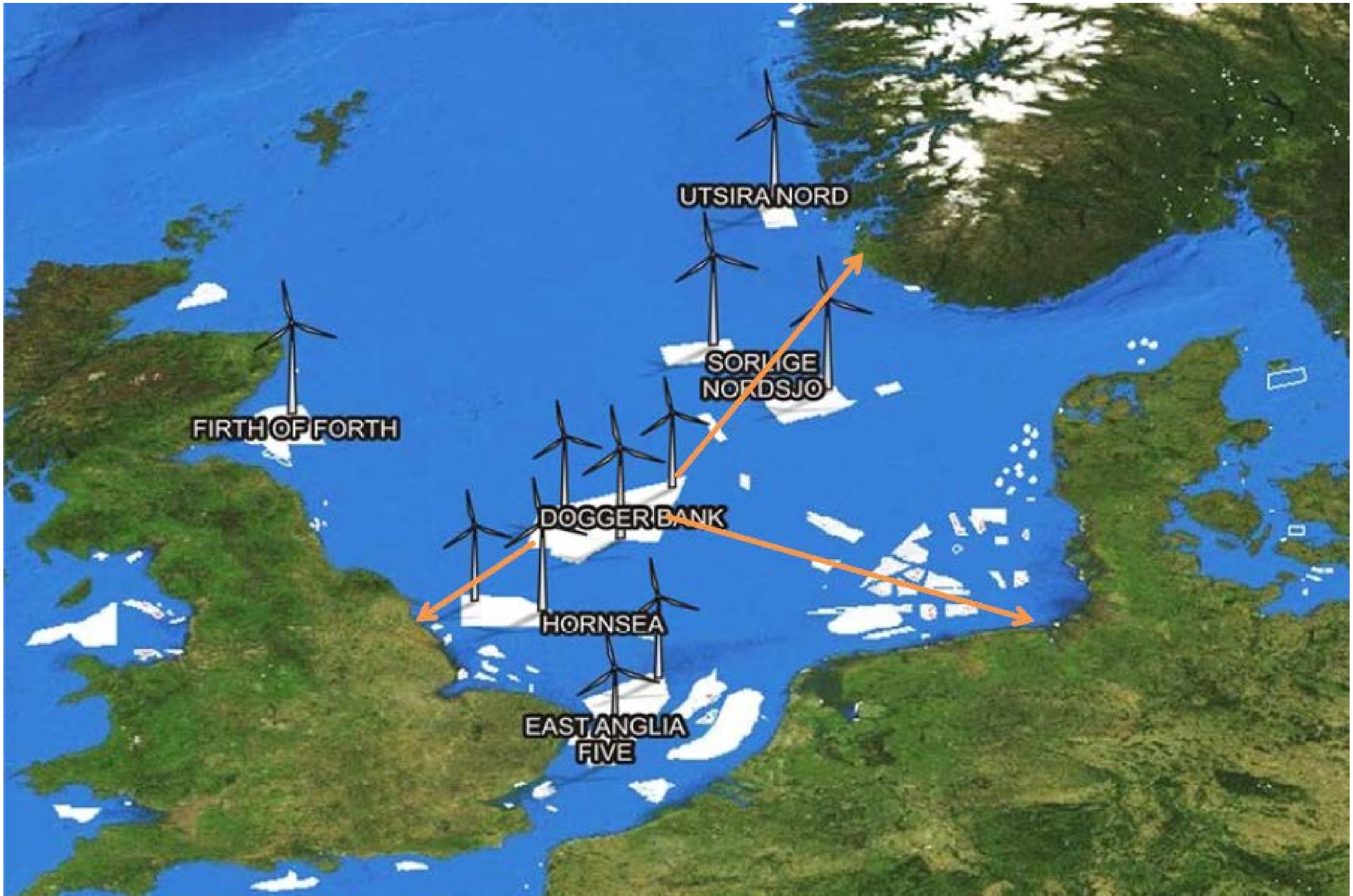
University of Strathclyde Engineering

- Annual Electrical power demand increased from just over 117,200 TWh to 153,600 TWh between 2000 and 2010 (an increase of ~30%) (U.S. Energy Information Administration, 2013).
- Greater pressure placed on development of sustainable energy sources with targets being set and some financial support/rewards in place
- Often necessitates long distance transmission
- Average distance of off-shore wind farms continues to increase
  - 2011 being 23.4km and that in 2012 being 29km from shore (EWEA 2011, 2012)
  - announced projects for installations up to 200km from shore



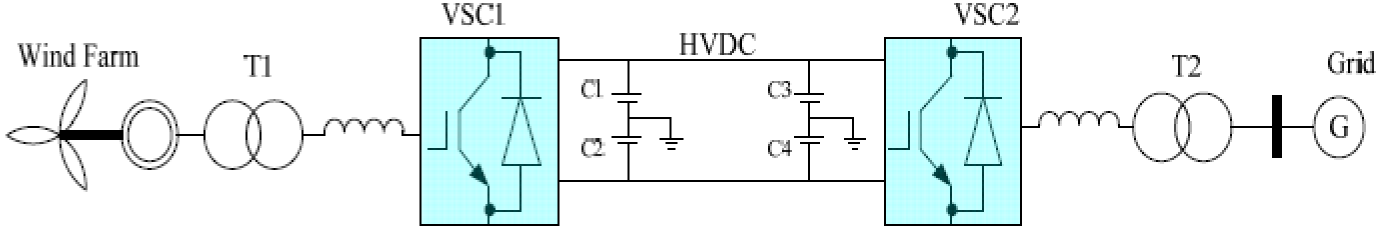
(EWEA 2012 annual report)

University of Strathclyde Engineering

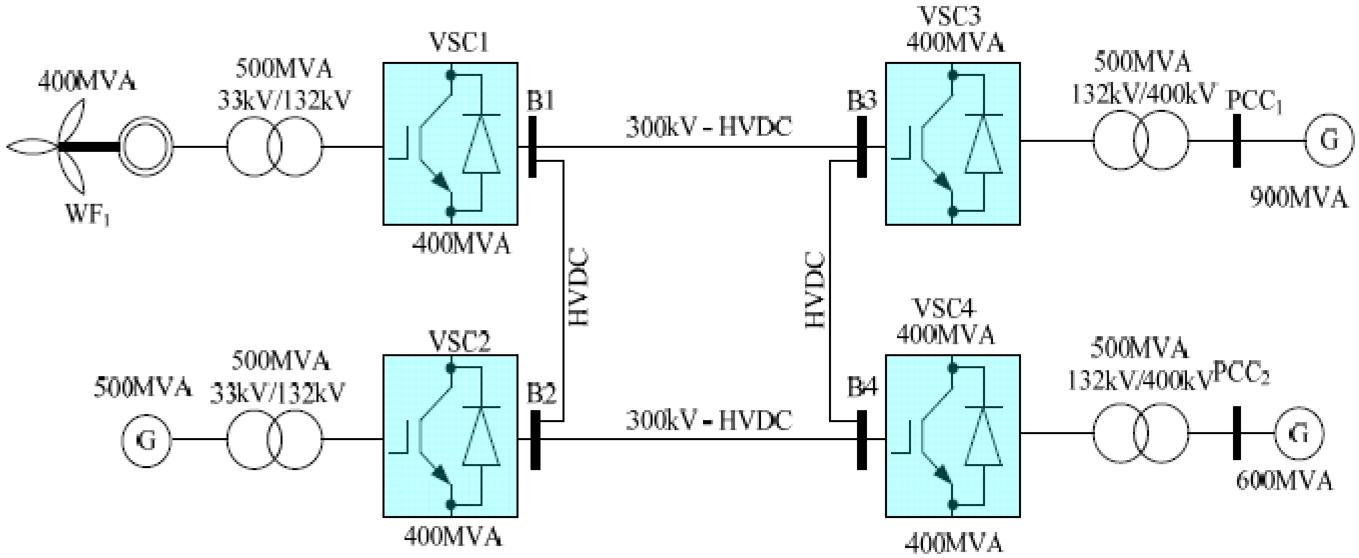


Where Next?

- Increasing wind penetration leading to a growing impact of wind farms on their networks
- Greater need for adoption of HVDC transmission in connection of large offshore wind farms and control of power injected onto the grid
- Use of HVDC to allows control of Voltage and reactive power injected into the grid with asynchronous connection between different AC grids
- Adoption of multi terminal HVDC connection to allow better power flow management amongst a number of interconnected grids instead of simply point to point connection



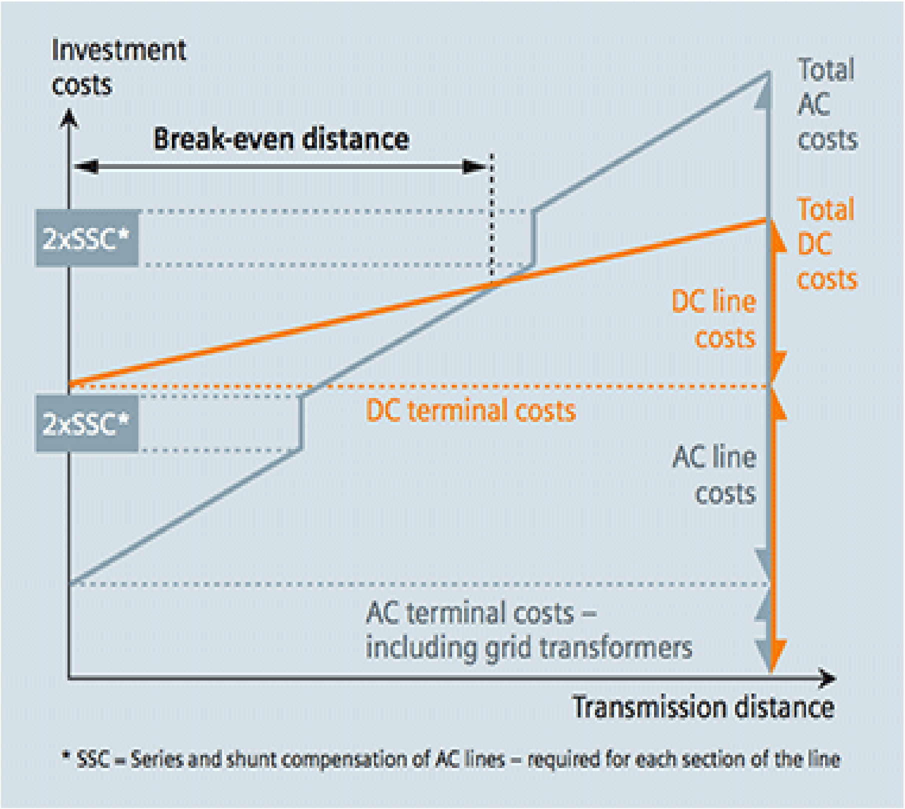
Multi-Terminal HVDC



- Allows better power management in event of severe faults in localised parts of the grid that would leave many without power using point to point connection
- Boost Electricity economy for countries with large renewables potential
- Needs better standardisation of grid code requirements across Europe

Why HVDC

Offshore wind energy projects are becoming more attractive, but a number of technological challenges still need to be resolved.



http://electrical-engineering-portal.com/download-center/books-and-guides/siemens-basics-of-energy/power-td-solutions

- Large amounts of reactive power required in HVAC to feed the capacitive charging current of the cables.
- For 1 GW of offshore wind farms and distances greater than 80 km the preferable way of transferring power to onshore is HVDC.
- There are a number of upcoming HVDC projects, especially in China
- Predominantly Thyristor based systems ~ 600kV, 6400MW
- Several IGBT based systems planned in Europe (mostly ABB)

HVDC Converter Technology

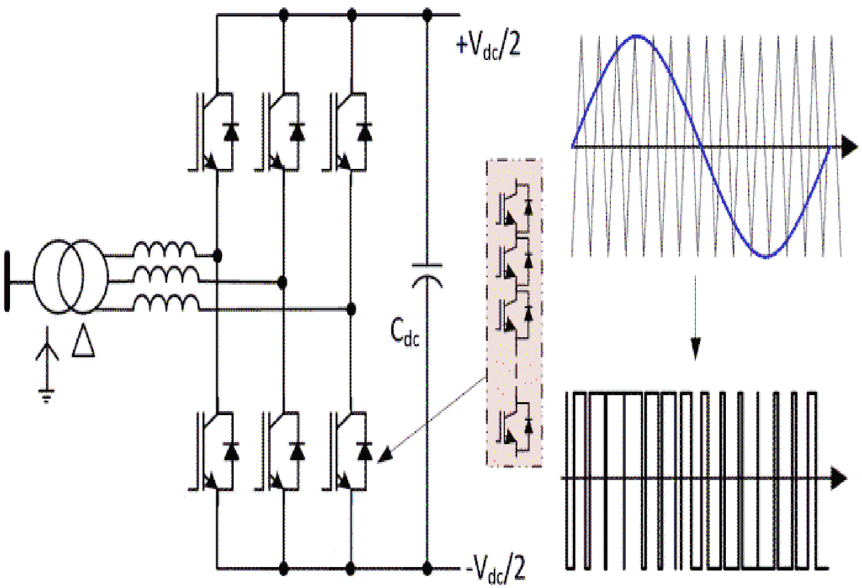
Line Commutated Converters

- Line Commutated Converters used for HVDC projects since 1950's.
- Use SCRs as the switching device, a method that lacks gate turn-off capability. The AC current needs to become zero in order to switch off.
- Not suitable for connection with weak AC networks. They need reactive power compensation in order to be functional.

Voltage Source Converters

- VSCs use self commutating devices such as IGBTs and GTOs that have voltage ratings close to 6.5kV
- Unlike LCCs , they provide rapid, independent control of active and reactive power.
- By using Pulse Width Modulation any phase angle or magnitude can be constructed
- Lower filtering requirements, thus improving the overall converter footprint.
- Black-start capability and no restriction on multiple infeeds

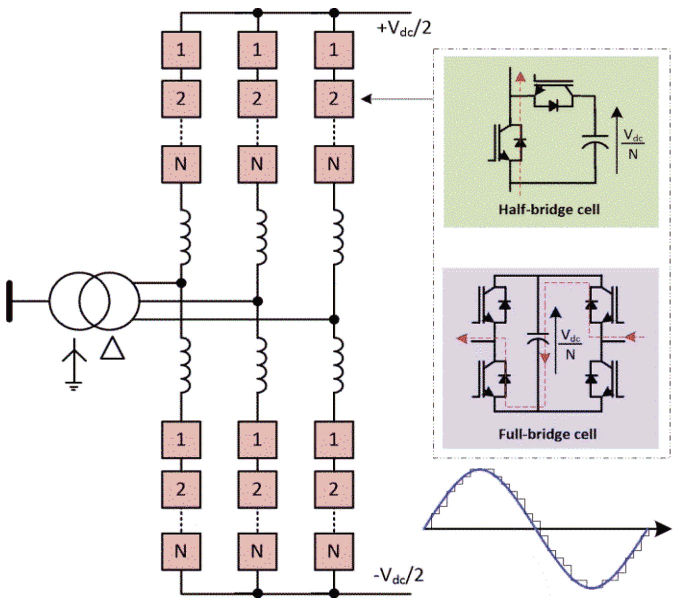
Earlier VSC Technologies



Two level half bridge VSC

- Two level and three level VSCs started become popular during the early 1990's
- High voltage IGBT devices allow the inverter output to be switched between the positive and negative DC poles (0.5Vdc) and (-0.5Vdc)
- The output voltage consists of series rectangular pulses with controllable width, thus making it possible to control the frequency, phase and magnitude.
- AC filters are used to eliminate the large harmonic content, but are reduced compared with LCC technology.

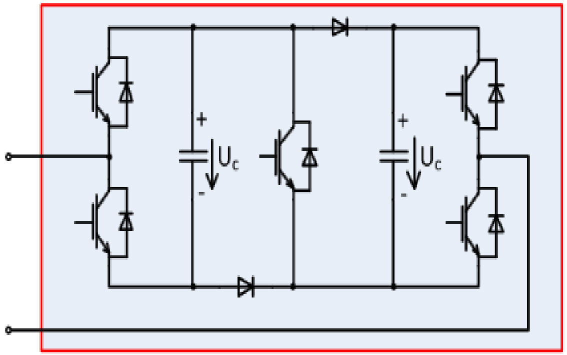
Modular Multilevel Converters



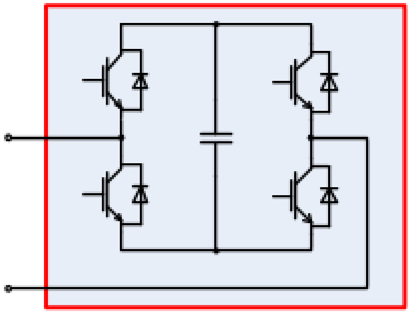
3 Phase Modular Multi Level Converter

- Earlier VSC designs were unable to meet the voltage requirements for HVDC due to low IGBT ratings.
- A series combination of sub-modules allows scaling to required HV levels
- The capacitor of each cell can accommodate a fraction of the DC link voltage.
- With the use of stepped modulation, intermediate voltage levels could be synthesized.
- The use of MMC results in improvements in power quality, filtering requirements and lower switching losses

Sub Module Topologies for MMC



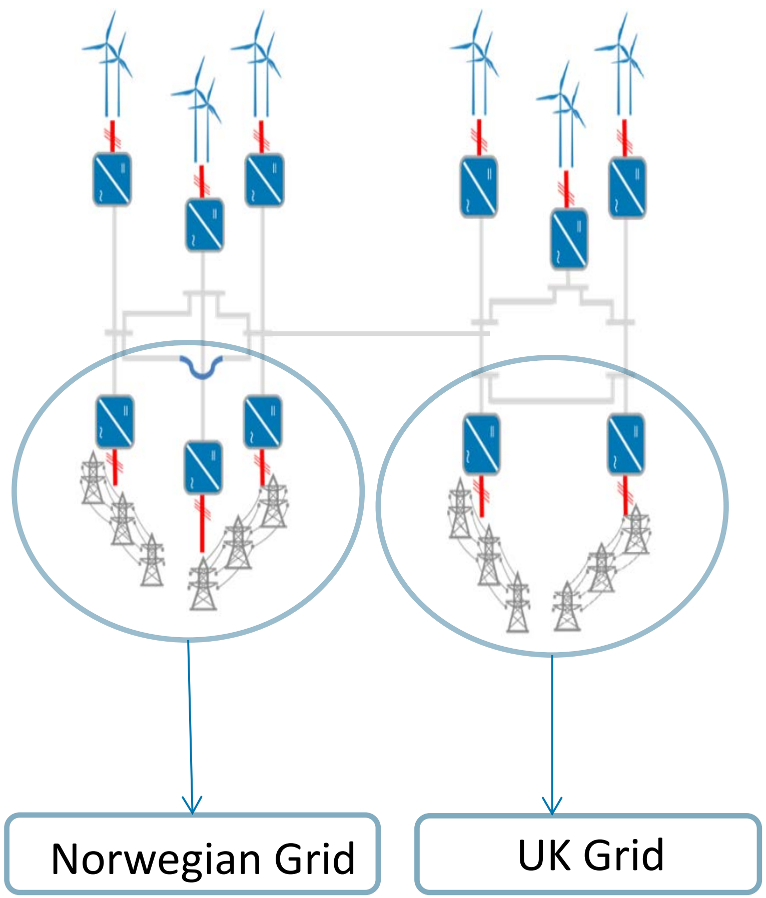
Clamp-Double sub-module
http://www.ptd.siemens.de/TransBayCable__HVDC_PLUS_Presentation.pdf



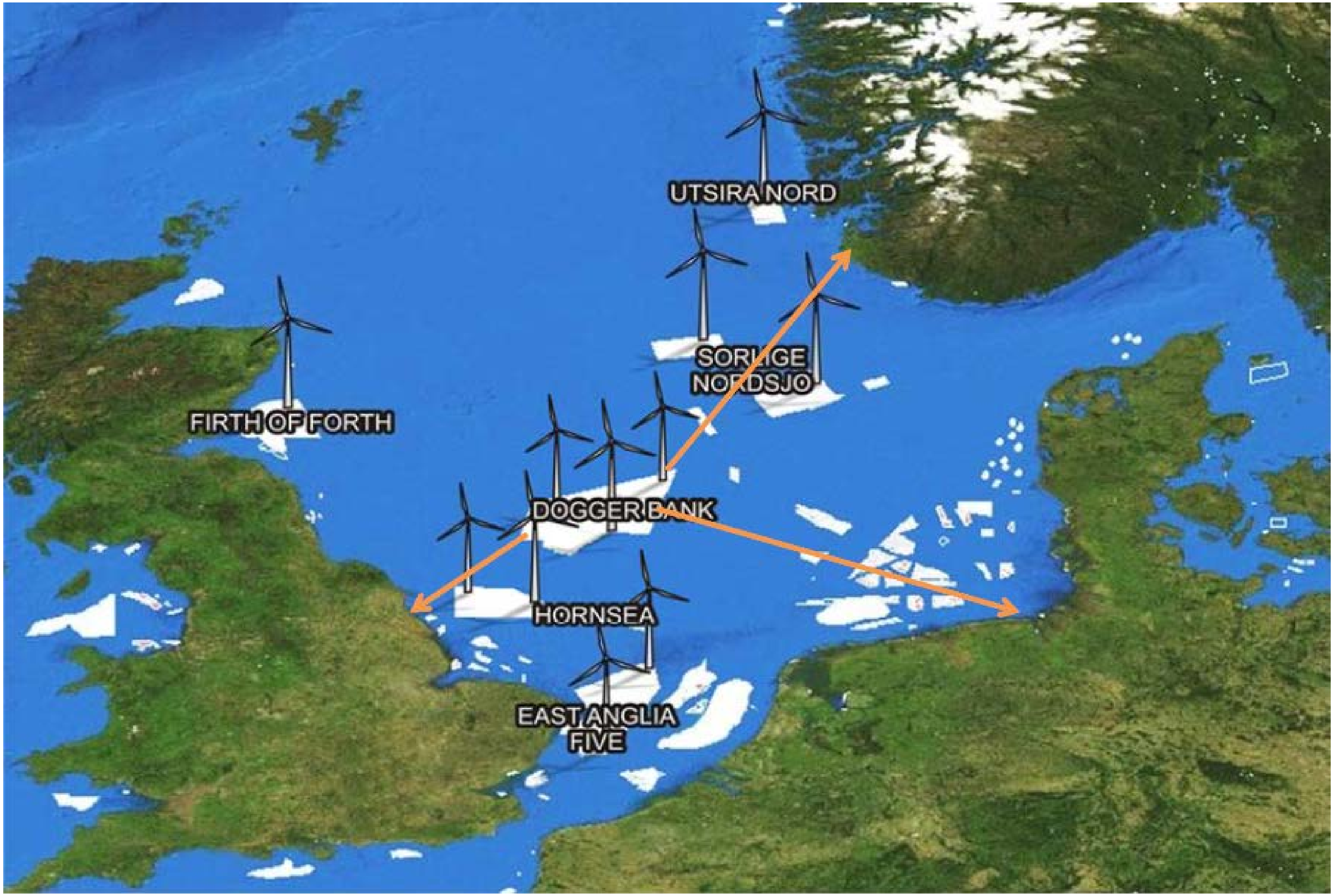
Full Bridge MMC sub-module
http://www.ptd.siemens.de/TransBayCable__HVDC_PLUS_Presentation.pdf

- Full Bridge sub-modules have been proposed instead of half-bridge. They provide the capability of DC-side fault protection.
- Conduction losses are larger due to additional semiconductor devices in the conduction path.
- The use of Clamp-Double sub-modules doubles the voltage capability of the converter compared with other arrangements.
- Can turn off DC pole to pole faults and has lower switching losses than the full bridge sub-module.

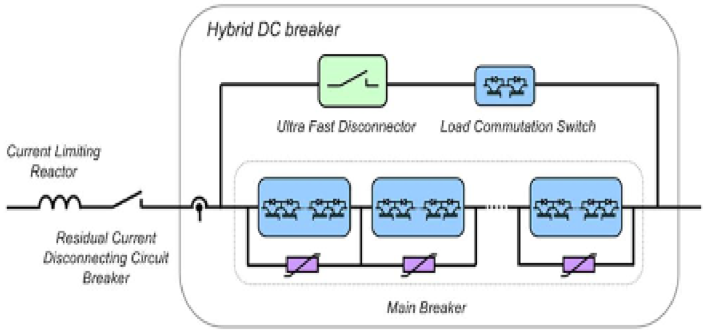
Offshore DC Grid connection



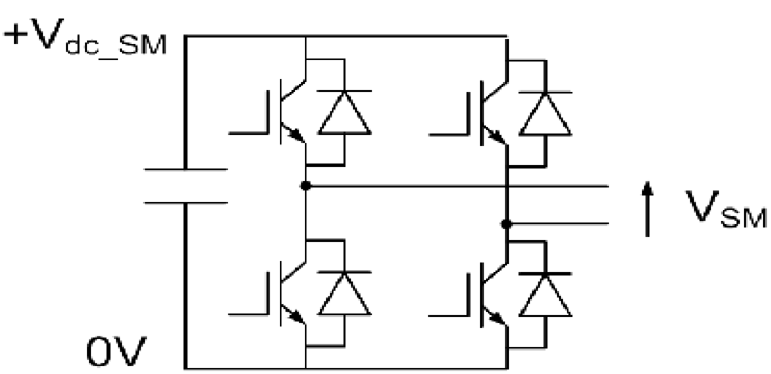
- Existing VSC HVDC connections are point-to-point.
- Considerations have been made for Multi Terminal DC connections (MTDC)
- They will be capable of bringing together geographically dispersed wind farms
- Offering transmission path for offshore wind power to the markets.
- Sophisticated control strategies need to be implemented for power sharing between the converters during normal operation as well as during faulty conditions.


UTSIRA NORD
SORLIGE
NORDSJO
FIRTH OF FORTH
DOGGER BANK
HORNSEA
EAST ANGLIA
FIVE

Protection issues for MTDC



Hybrid HVDC Breaker.
http://new.abb.com/about/hvdc-grid



Full Bridge MMC sub-module
http://new.abb.com/about/hvdc-grid

- HVDC offshore grids consist of multi terminal converter arrangement which are regarded as a cost effective way to connect large offshore projects to onshore networks.
- DC to ground faults in a meshed HVDC grid could be isolated with the use of multiple protection zones, thus increasing the reliability of the overall system.
- In DC Grids a fault would lead to a rapid increase in fault current and a voltage dip would appear in the system.
- DC Breaker technology currently developing could be proven a reliable choice to selective fault clearing .
- Alternatively, use full bridge sub-modules with fault blocking capability.

Summary

- Ever rising electricity demand is fuelling a growth in renewables
- Increasing wind penetration leading to a growing impact of wind farms on their networks
- Advances in power electronic devices and their improved controllability are making the adoption of larger scale wind derived energy plausible on existing AC networks
- R&D to further develop wind power plant models and control strategies to demonstrate and validate their ability to provide ancillary services and support system security
- We shall be working in this area over the next 3 years, looking at topics and technologies outlined hoping to provide a solution to make offshore wind easier to integrate with AC networks with better network support.

Thank You

Questions?

University of Strathclyde Glasgow