Power Converter & Electrical machine technology for Renewable Energy

Micro-Grids and Distributed Energy Resources (MIDERCON)

C Smith, 19th September 2007

CONVERTEAM
THE POWER CONVERSION COMPANY

Contents

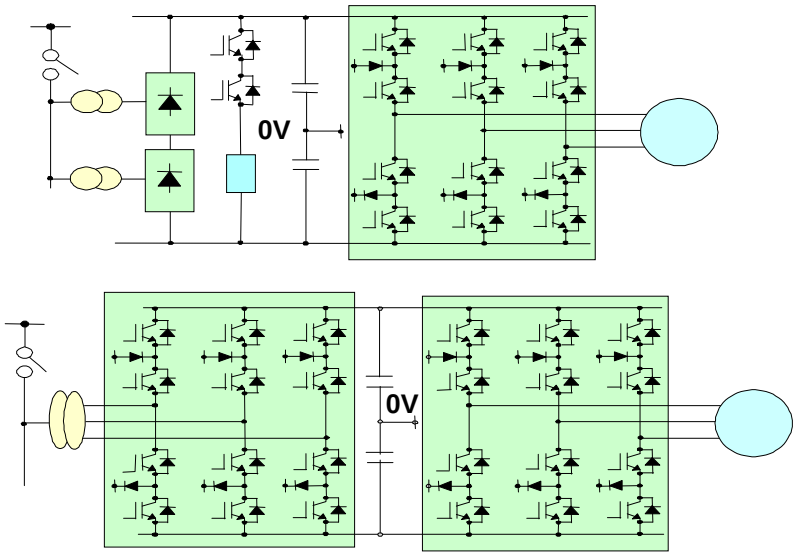
- Converter technology for Wind
- Future Electrical machine technology for Wind
- Use of Converters in the “Wet” renewable industries

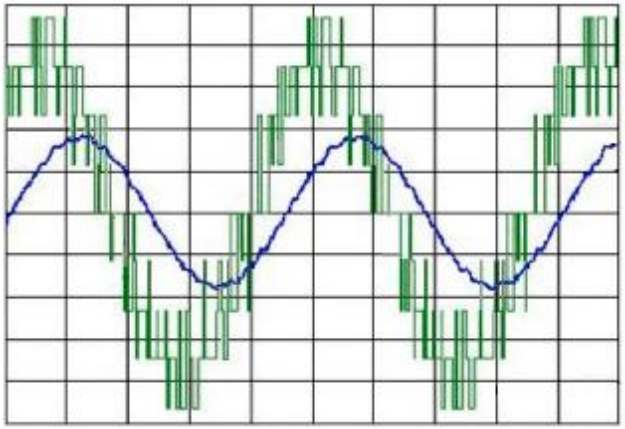
Converter Technology

Introduction to Power Converters

- **Comprise of:**
  - Generator bridge
  - Network Bridge (Known as an Active Front End if IGBT based)
  - DC link
  - Dynamic Breaking resistor
  - Filters
  - Line Reactors
  - PWM control

Modern MV Converters

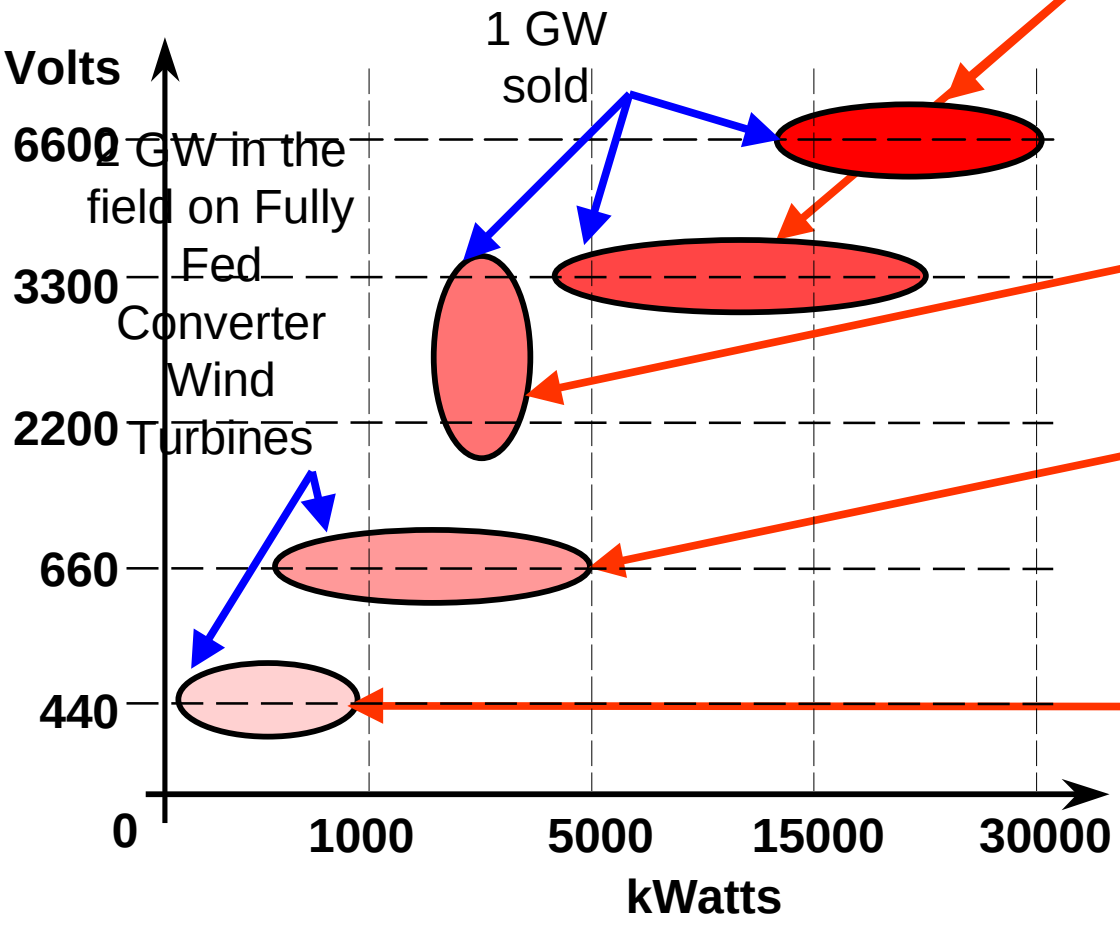


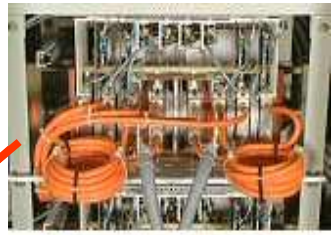


- A MV range of drives, using press pack IGBT " PPI " devices above 3300 VAC, and flat pack IGBTs at lower voltages, has been developed and rated at :
  - 2.3, 3.3 and 6.6 kV & 1.8 to 32 MW.
  - PPIs only need low power 10 A gate pulses unlike IGCTs needing 4000 A.
- This technology :
  - Significantly reduces the overall size.
  - Gives a very robust drive.
  - Reduces the rated motor current.
  - Requires less cabling volume.
- The three level NPC topology is used :
  - To improve the motor voltage waveform.
  - To have very low harmonic content in the motor's current and the AC supply current.
  - Note filter still required to meet grid codes

Converter Technology ranges

CVT has a complete range available.
All types are available with DB choppers or active front ends AFE for stopping the motor.





Liquid cooled. MV7306 and MV7612-3 level inverters.

Liquid cooled. MV7203-3 level inverters.

Liquid cooled. MV3000 2 level inverters.

Air cooled. MV3000 and LV7000 products

Control Strategies of Power Converters

- **Wind Power**
  - Generator Bridge
    - Uses PWM to control DC Link Voltage
    - DC Link Voltage controlled by controlling generator power
  - Network Bridge
    - Extracts required power from the DC link
    - Provides specialised control features e.g. Grid Fault ride through
- **“Wet” Renewables**
  - Network Bridge
    - Aids control of DC link
    - Provides specialised control features e.g. Grid Fault ride through
    - Power smoothing for wave applications

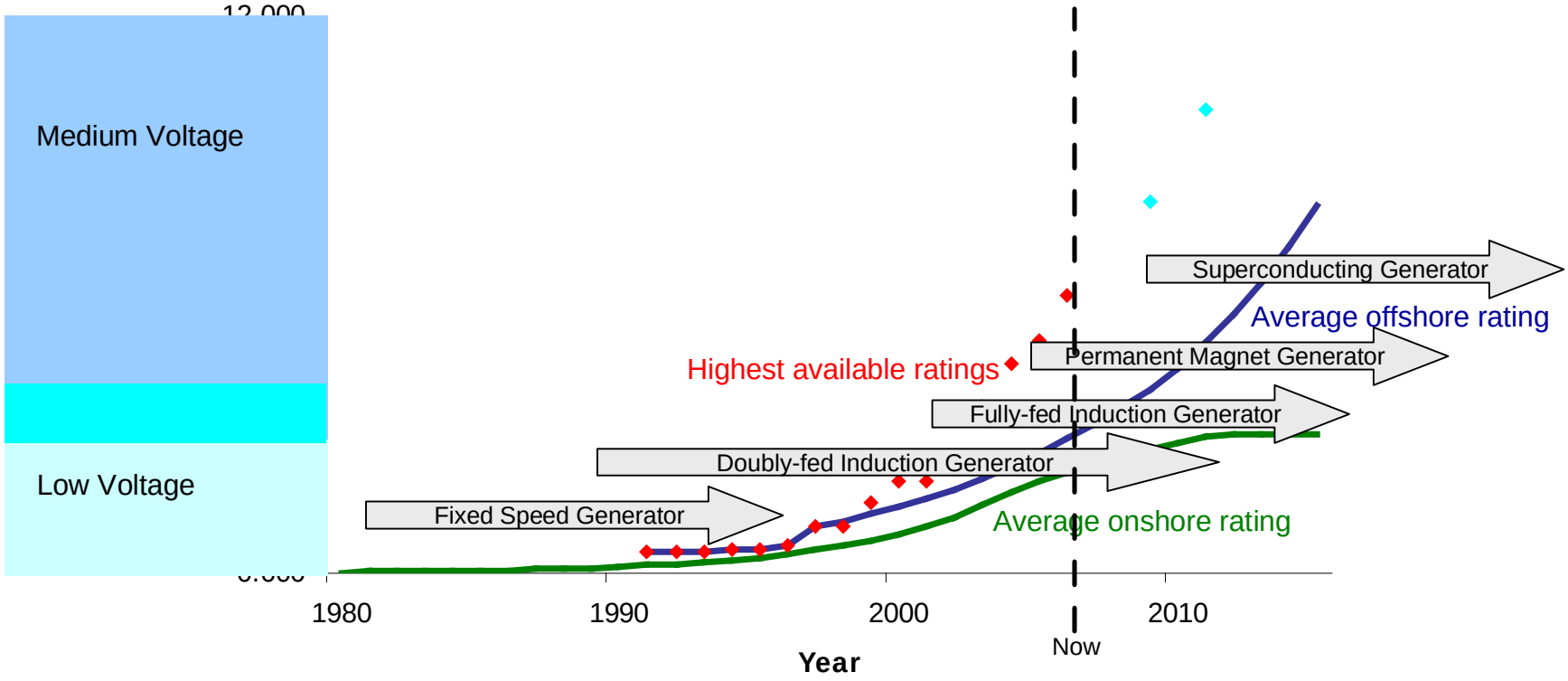
Typical MV Converter cubicle

1. Automation and interfaces.
2. Drive controller and cooling.
3. Mains inverter rated at 6 MW to supply variable power factor.
4. Motor inverter rated at 6 MW for any type of electrical machine.
5. DC link capacitors, DB chopper and DB resistor depending on application.

Generator technology development

Dominant generator technologies
Highest available power ratings ~ doubling every five years

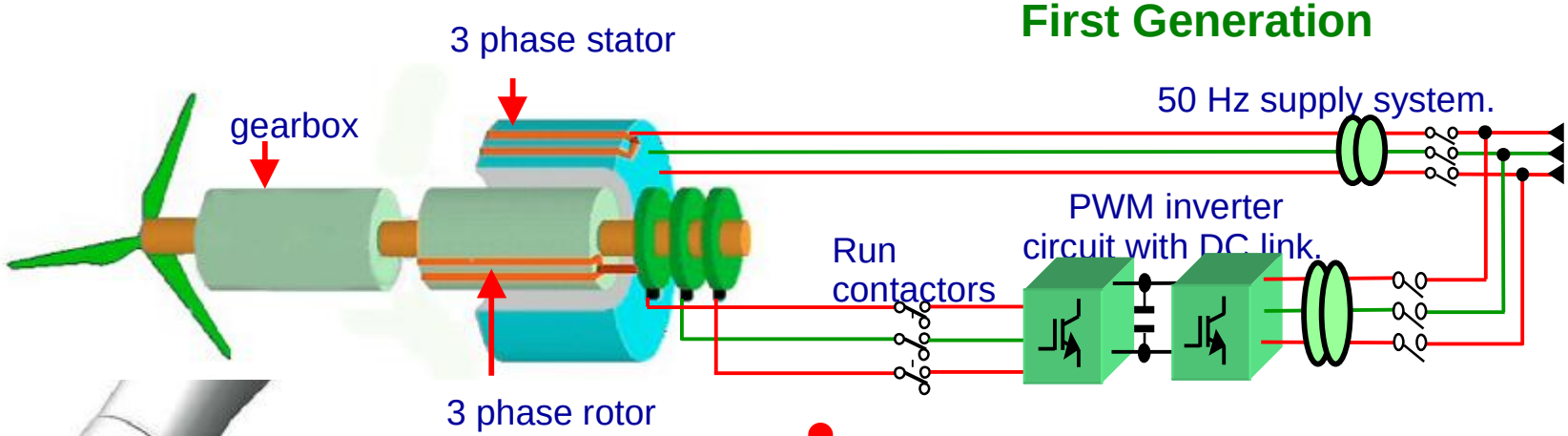
- **Driven by economics; will continue offshore**

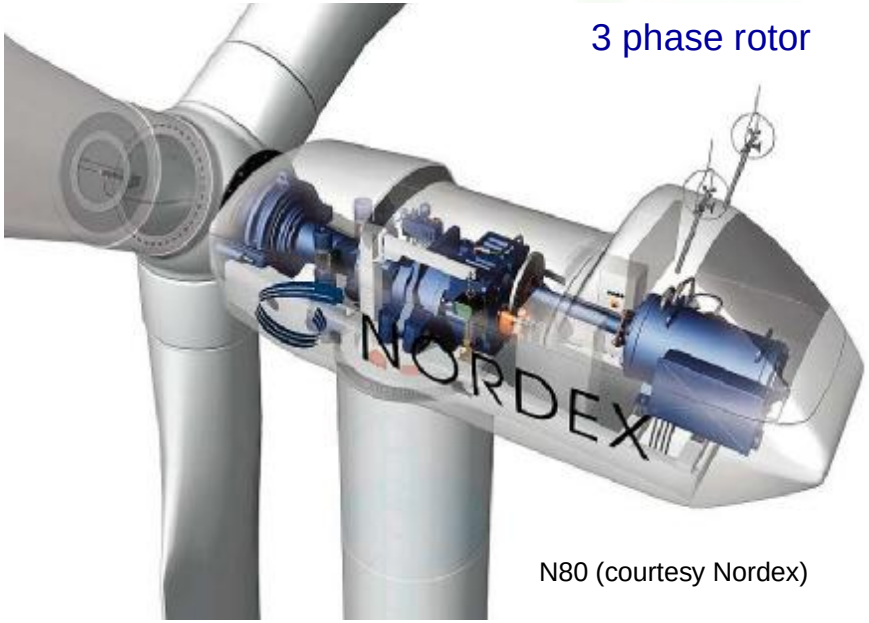


- **Around 2015, DD-HTS cost advantage even at 2MW - 3MW onshore**

Wind – First Generation

First Generation





N80 (courtesy Nordex)

- **First Generation - Doubly-fed Induction Generators (DFIG), LV, AC/AC converter, Medium Speed, 1.5MW turbines pushing 5MW**
- **For UK Offshore?**
  - **Grid faults kill stators and gears**
  - **Excessive wear on sliprings**
  - **Power quality measures needed**
  - **Maintenance costs escalate**
  - **Full grid compliance difficult**

DFIG

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This is the traditional approach and offers these benefits: -

- Minimum capital and running cost of generation and power conversion.
- Minimum power losses (maximises revenue, selling of kWh).

However, it has the disadvantages of: -

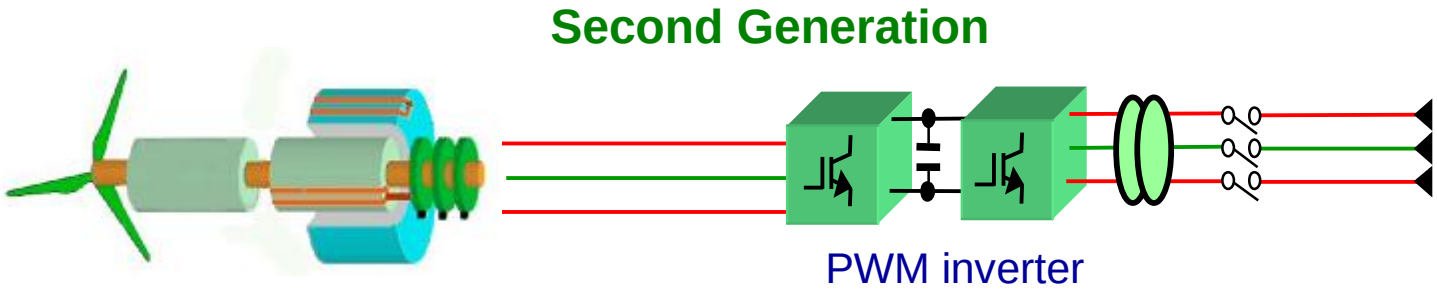
- Severe Grid Fault Ride though ability not proven
- Additional Power Factor Correction required to meet Grid code Power Factor operation.
- Machines have slip rings and converters normally have rotor control high power contactors for starting. Both require regular maintenance on offshore equipment increasing maintenance costs

Technology is still evolving - in particular crowbar technology

DFIG Grid Fault Ride Through

- **Not previously a requirement in UK or Europe**
- **Excitation is governed by the supply during normal operation, but the generator becomes self excited when the supply is lost or suffers a major voltage dip. As a result the frequency control cannot be guaranteed**
- **Very limited voltage support from the converter. (Maximum 1/3 of power)**
- **Control strategies based in protection and isolation of DFIG during the fault. With rapid reconnection after fault clearance**
- **However published site data shows DFIG's with limited fault ride through (20s recovery)**
  - NWPC Conference 22nd/23rd May 2006, Paper Titled "Recorded Fault Ride Through Capability for Two Types of Wind Turbine Generators", with authors Anton Dahlgren, Charlotte Klippel & Åke Juntti, Olof Samuelsson

Second Generation – Fully Fed Converters



- **Second Generation - Induction Generators (FFG), LV AC/AC or AC/DC converter, Medium or Low Speed, 2.3 & 3.6MW turbines**
- **For UK Offshore?**
  - **Generators become massive**
  - **Structural and installation costs escalate**
  - **LV cabling must be considered**

Fully Fed Converters

Advantages

- Good quality sinewave output with the addition of sinewave filter and correct architecture of network side converter.
- Ability to control power factor of generator as ‘seen’ by supply.
- Ability to ride through power system faults with control of the leading VArs into the fault meeting grid code fault ride through requirements (assuming that drive controls are designed to operate as an integrated farm and turbine auxiliaries are designed to ride through short time, up to 3 second, outages once WTG is up and running).
- Minimum cost of maintenance (fewer wearing and moving parts to maintain, e.g. rotor contactors, slip rings and brushes).
- Minimum requirement for additional power factor correction to meet grid code normal and transient load change operation.
- Easy to synch all units

Fully Fed Converters

Disadvantages

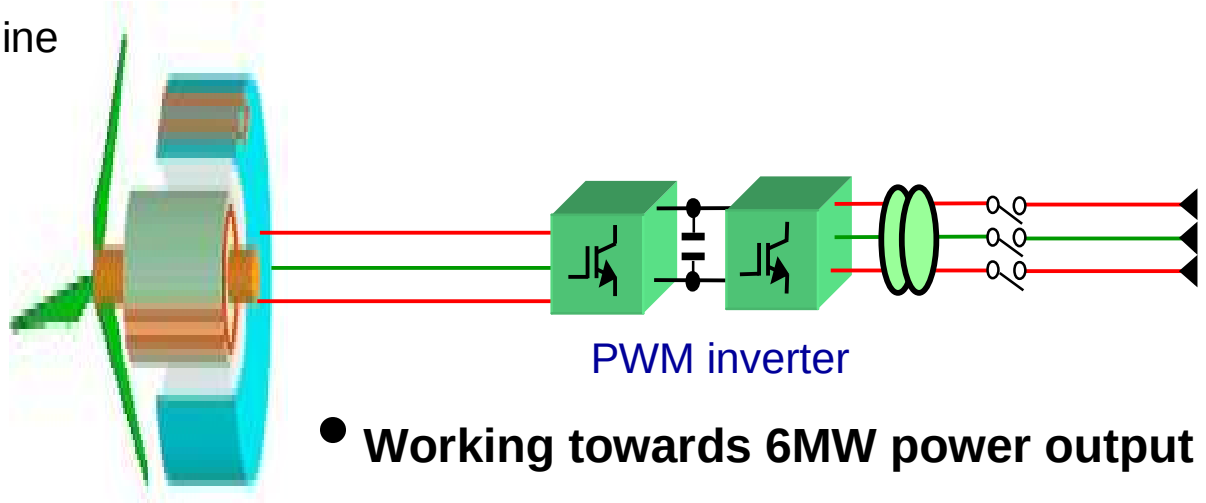
- Slightly lower efficiency (all generator power goes through converter, but without the losses of power factor correction equipment).
- Higher capital costs of WTG (but offset by lower power factor correction and switchgear costs).

Future Electrical Machine Technology

Permanent Magnet Generators

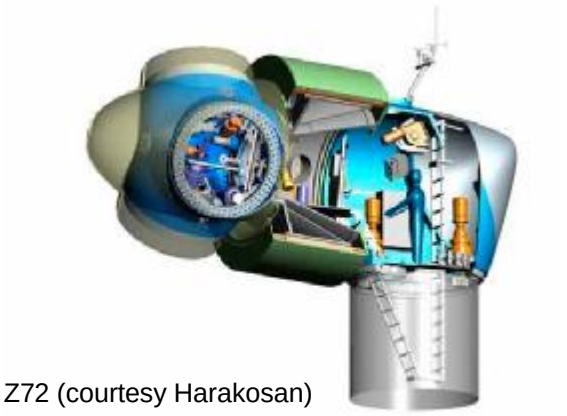
Permanent Magnet Machine

Multibrid (courtesy Prokon Nord)



PWM inverter

- **Working towards 6MW power output**

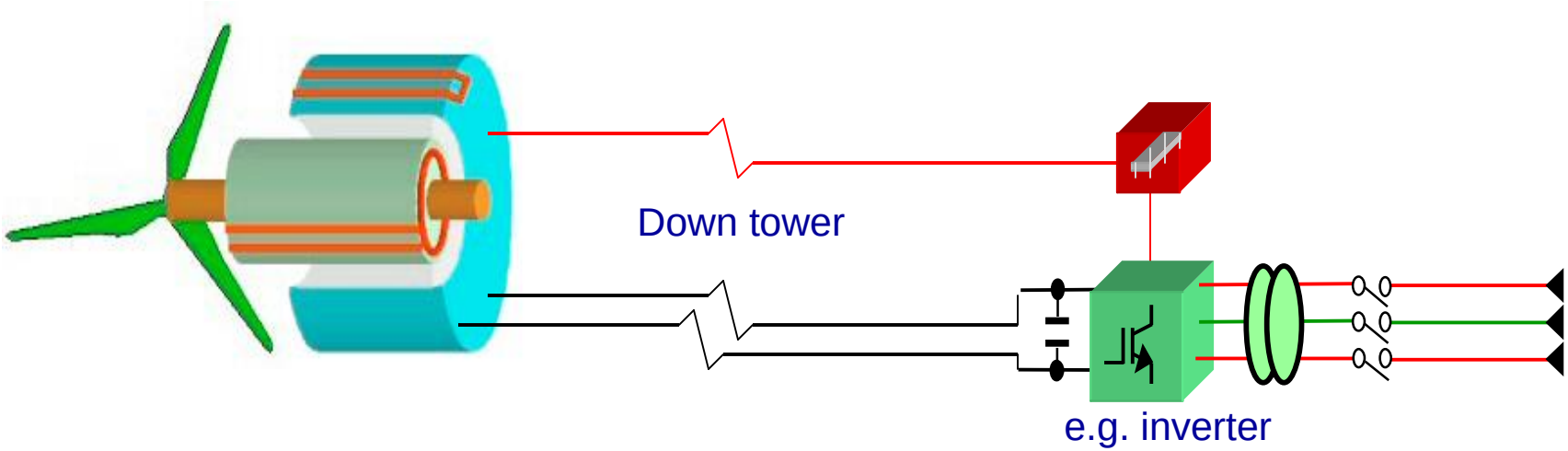


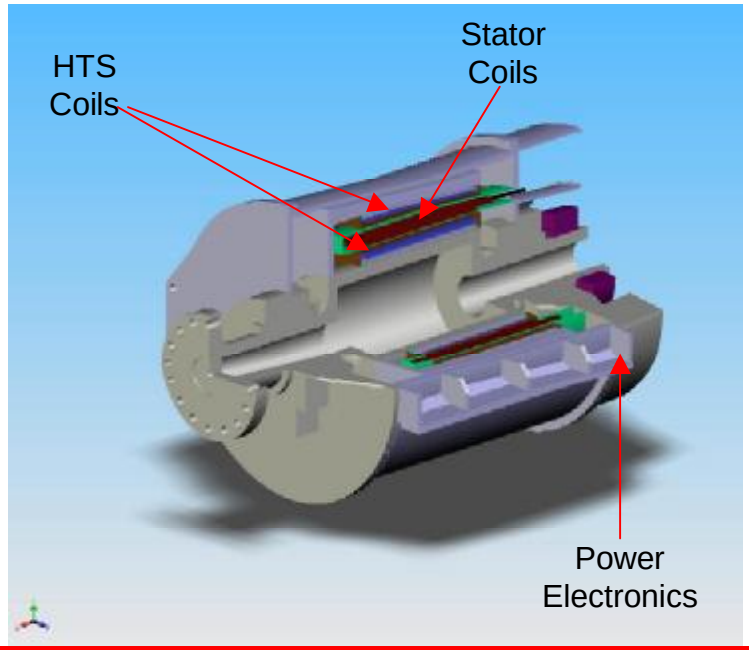
Z72 (courtesy Harakosan)

Direct Drive PM Wind Generators

- **Direct drive**
  - No Gearbox
  - High Reliability – very important for offshore!!!
  - Low Noise
- **High efficiency**
- **Fully fed converter**
  - Independent control of
    - Optimisation of PM generator magnetization
    - Power factor and harmonic control to system
- **Typical ratings 2-6 MW**
- **Range of 3-5 MW Direct Drive Permanent Magnet Generation in manufacture 2007**

High Temperature Superconducting





HTS 'Brushless DC' Generators (SCG)

HTS Wind Generators

- **Synchronous generator using High Temperature Superconducting (HTS) windings**
  - Rotor field winding using HTS coils cooled to 35 K (-240°C)
  - Stator windings at “normal” temperature
- **Superconducting coils conduct electric current indefinitely without loss when cooled below a critical temperature**
  - Power for refrigeration is small compared to the rotor losses in a conventional machine
- **HTS coils can produce very high magnetic flux density**
  - Leads to smaller, lower mass generator (<40% equivalent mass today)

HTS Benefits for Wind Power

- **No gearbox**
  - High reliability
  - Low maintenance
  - Very low noise
- **Lower cost than PM at high ratings (>6 MW)**
- **Low mass**
  - 50% of mass of PM generator
  - 25% of mass of wound pole generator
  - Reduced tower and foundation cost
- **Higher efficiency**
  - Part load efficiency very high – important for wind power
- **Typical Ratings 6 - 10+ MW**
  - Integrated converter
  - Medium voltage AC or DC output
- **Fewer turbines per wind farm**
  - Lower installation and operating costs

HTS vs Permanent Magnet

HTS Advantages

- **Lower size and mass**
- **Simpler construction, low component count**
  - No laminations in stator – space for teeth can be filled with copper
  - No large numbers of magnets to attach
- **Lower cost**
- **Unity power factor operation**
  - Smaller converter

HTS Disadvantages

- **Cryocooler needs to be powered at all times (about 7 kW)**
- **Both HTS & PMG cannot weaken field as a result overspeed must be limited**

“Wet” Renewable’s

“Wet” Renewables

- **Many Concepts for mechanical & electrical equipment:**
  - Wave
  - Tidal
  - Ocean Current
  - Rotational Generators
  - Linear Generators
- **Generator and Converter technology “Proven” in most instances.**
  - Oil & Gas experience provides COTS products
- **However …….**

Each application has unique challenges that require significant System integration expertise

OPT PowerBuoy

- **Surface**

  Point Absorber

  Ocean Power Technologies (OPT)

  - 150kW
  - Various Installations

This Point Absorber takes energy out of the waves via a float which reciprocates in response to changes in wave height. As the float rises and falls the hydraulic cylinder connected to it pumps oil through a motor generator set converting the motion to electrical power.

New topologies under investigation with OPT

OPT PowerBuoy Challenges

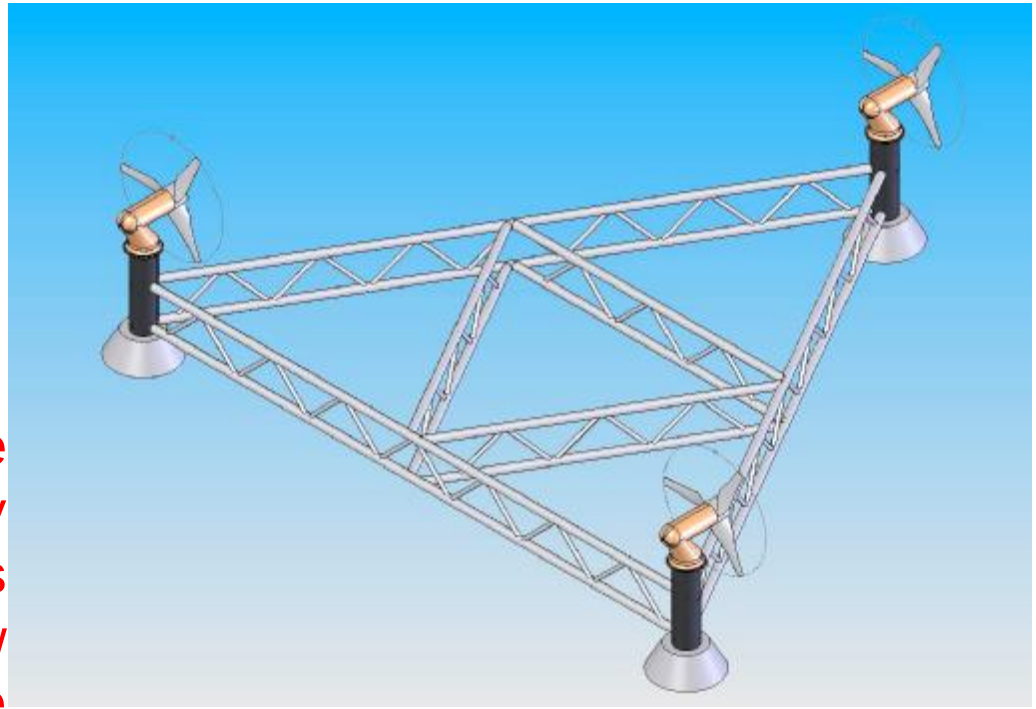
- **Power Electronics inside PowerBuoy.**
- **Technical challenges**
  - Vibration
    - Solutions from military and commercial shipping
  - Power smoothing cyclical power from waves

- **Challenges in liner generator design**
  - Weight reduction
  - Efficiency
  - Cost

Wet Renewables - DeltaStream

Sub sea

- **Pod / Turbines**
- **3x 400kW generators, power converters, automation and control**



Made up of three identical turbine pods, fixed in a triangular position by the base plate. The shape is designed to maximise the water flow across all turbines. The pods are turned to face the tidal flow during slack water, though each one can be trimmed to improve power sharing. Raw power (11kV) is transmitted to shore for conversion into grid compliant power.

Delta Stream Challenges

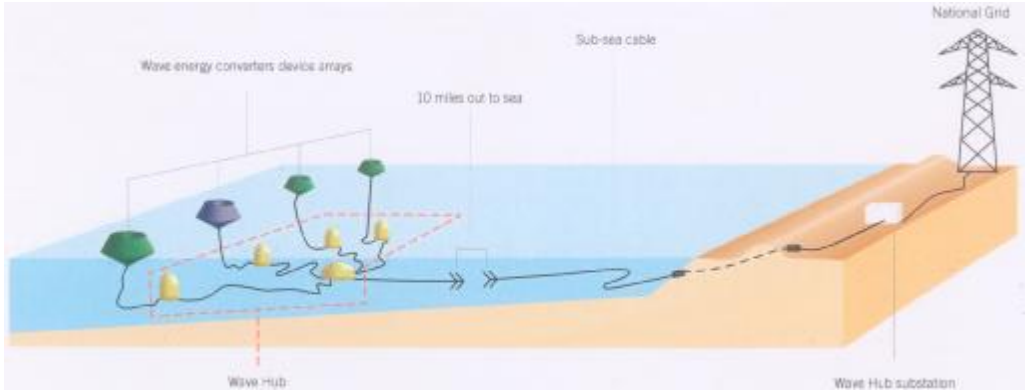
- **Distance of converter from the generator is significant (>10km)**
- **Cable design becomes dominant**
  - Capacitance
  - Can the cable self excite the generator during a cable fault
- **Control of Generator to achieve maximum efficiency**

Ocean Current Generator

- **Sub Sea Ocean Current**
- **This powerful device uses ocean current or tidal flows. Suitable sites are often far from shore < 50km and in deep water.**
- **Challenges**
  - Control of vessel to extract maximum power
  - Cable design
  - Mooring the craft

OFFSHORE WAVE FARM

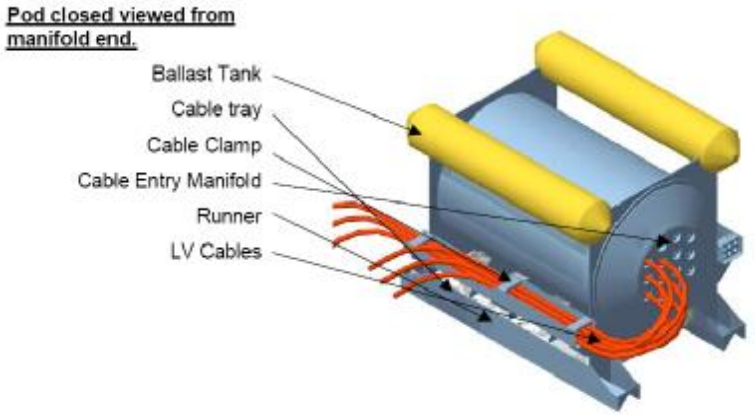
- **Wav Hub – North Cornwall**
  - Strategy
    - First wave farm test site
  - Technical
    - 4 x 5MW connections
    - Subsea connection modules
  - Policy
    - Allow developers to prove farm operation
    - Open to any developer irrespective of technology

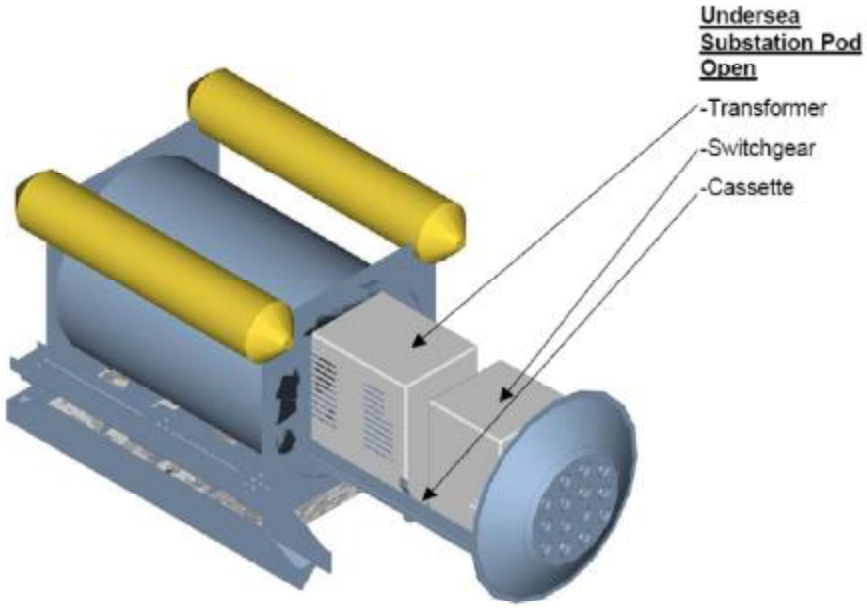


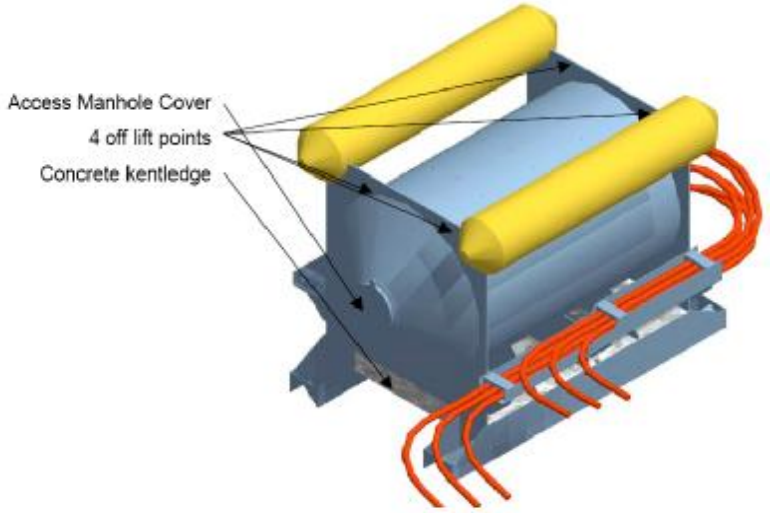
- Challenges
  - Plug & Play mechanical devices. What is your electrical design!
  - Transients need to be understood for each technology

Sub Sea Module

Various sub sea modules will be required for farm connections and to locate the power conversion systems close to the generating device. Converteam have develop this technology for the oil industry for depths > 1000m.







Conclusions

- **Fully fed and DFIG continue to develop**
  - Flexibility
  - Fault ride through
  - VAr support
- **Generator technology moves to PMG then HTS**
  - Lowering cost
  - Improving efficiency
- **“Wet” Renewables**
  - Many of the technological challenges have been faced and overcome by the Oil & Gas industry
  - Products relatively mature
  - System Integration skills become critical to success

Thank you for your attention

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