Scaled Hardware Implementation of a Full Conversion Wind Turbine for Low Frequency AC Transmission

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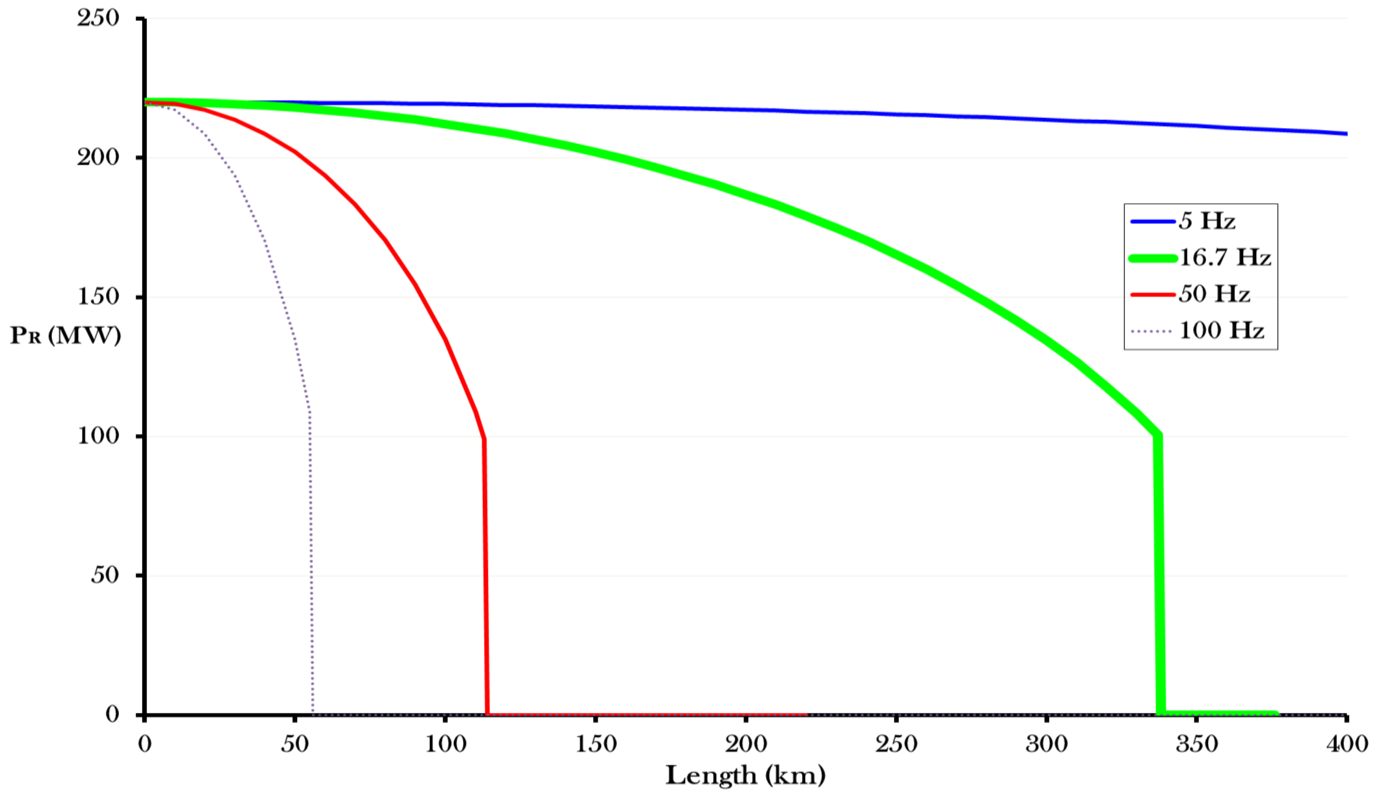
Presentation Overview

- Background to LFAC transmission for offshore wind
- Design of an LFAC grid compatible wind turbine
- Onshore VSC design

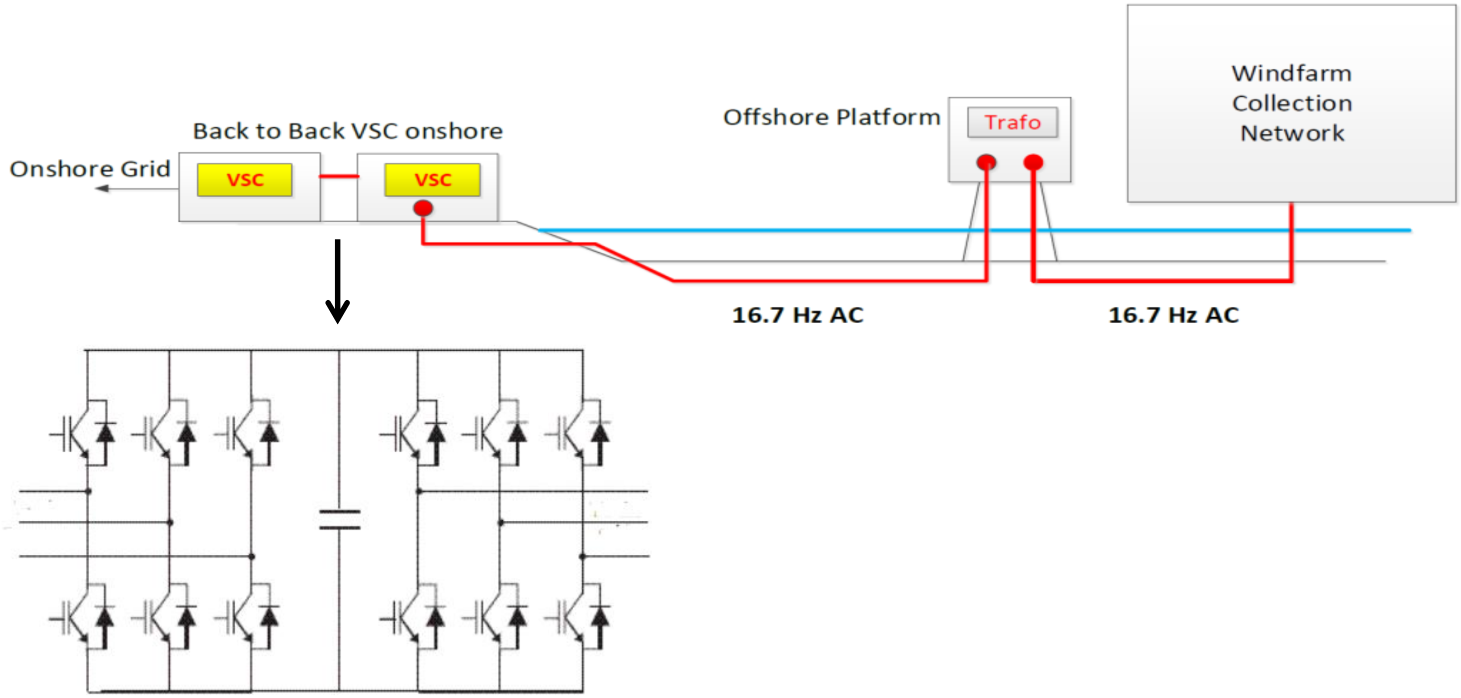
Why Low Frequency AC?

Transmission capability stability limit:

$P_{max} = \frac{V^2}{X}$; $X = 2\pi f L$; $\downarrow f, \downarrow X; \uparrow P_{max}$



Onshore Frequency Changer



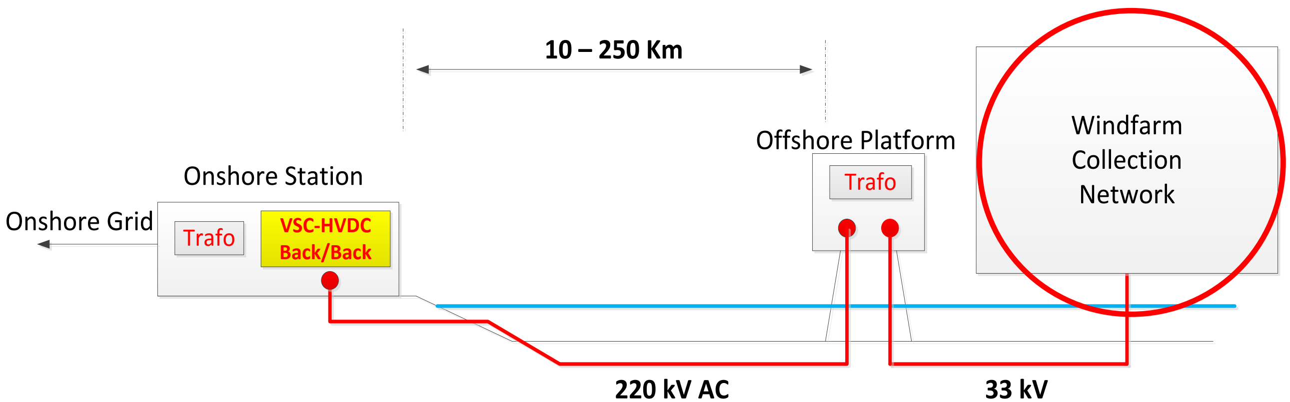
Back to Back VSC converter – Decoupled AC – DC – AC conversion

Ruddy *et al.* 2016 “Low Frequency AC transmission for offshore wind power: A review”
Fischer *et al.* 2012 "Low frequency high voltage offshore grid for transmission of renewable power"
Jafar *et al.* 2014 "Low Frequency AC Transmission for Grid Integration of Offshore Wind Power"
Olsen *et al.* 2014 "Low Frequency AC Transmission on large scale Offshore Wind Power Plants, Achieving the best from two worlds?"

Wind Turbine Collection Network

- Real Time Simulation (RTS) UCD
- <u>Step 1</u> : Can you design a full conversion WT at 16.7 Hz ?

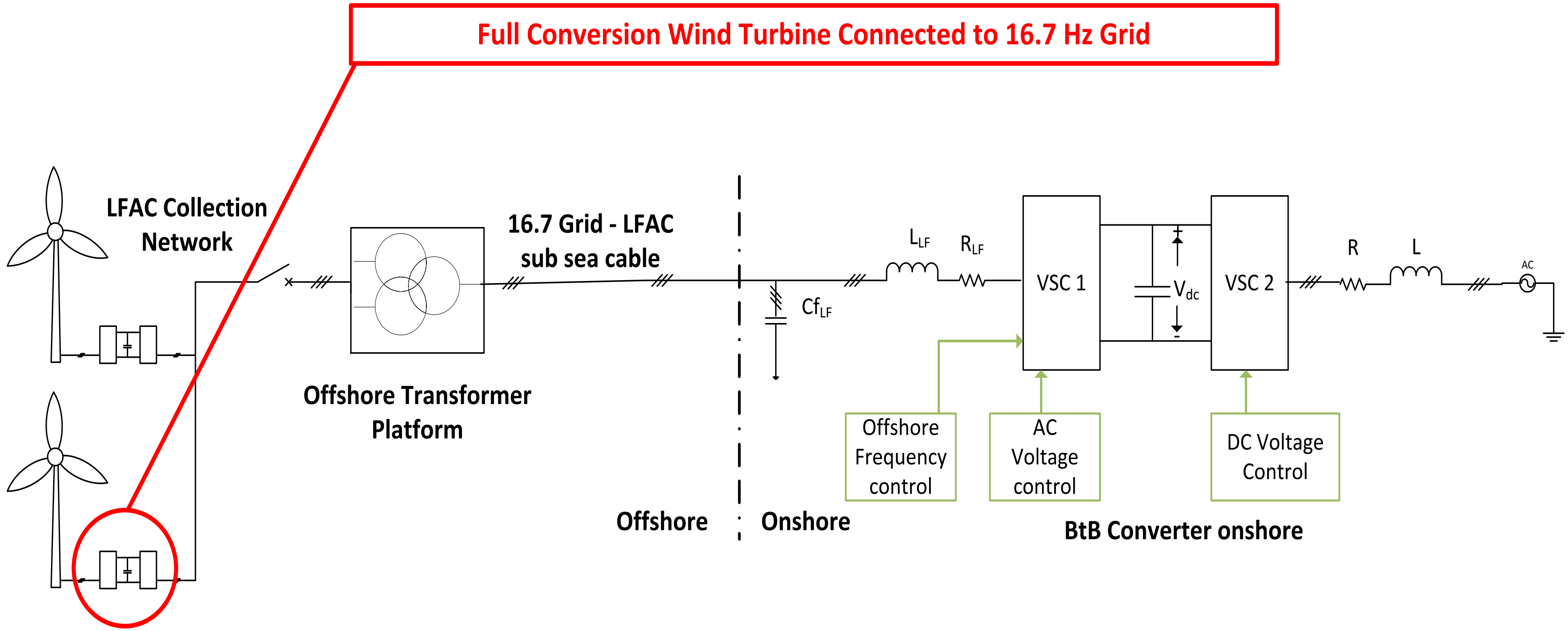
Step 1 Design Wind Turbine



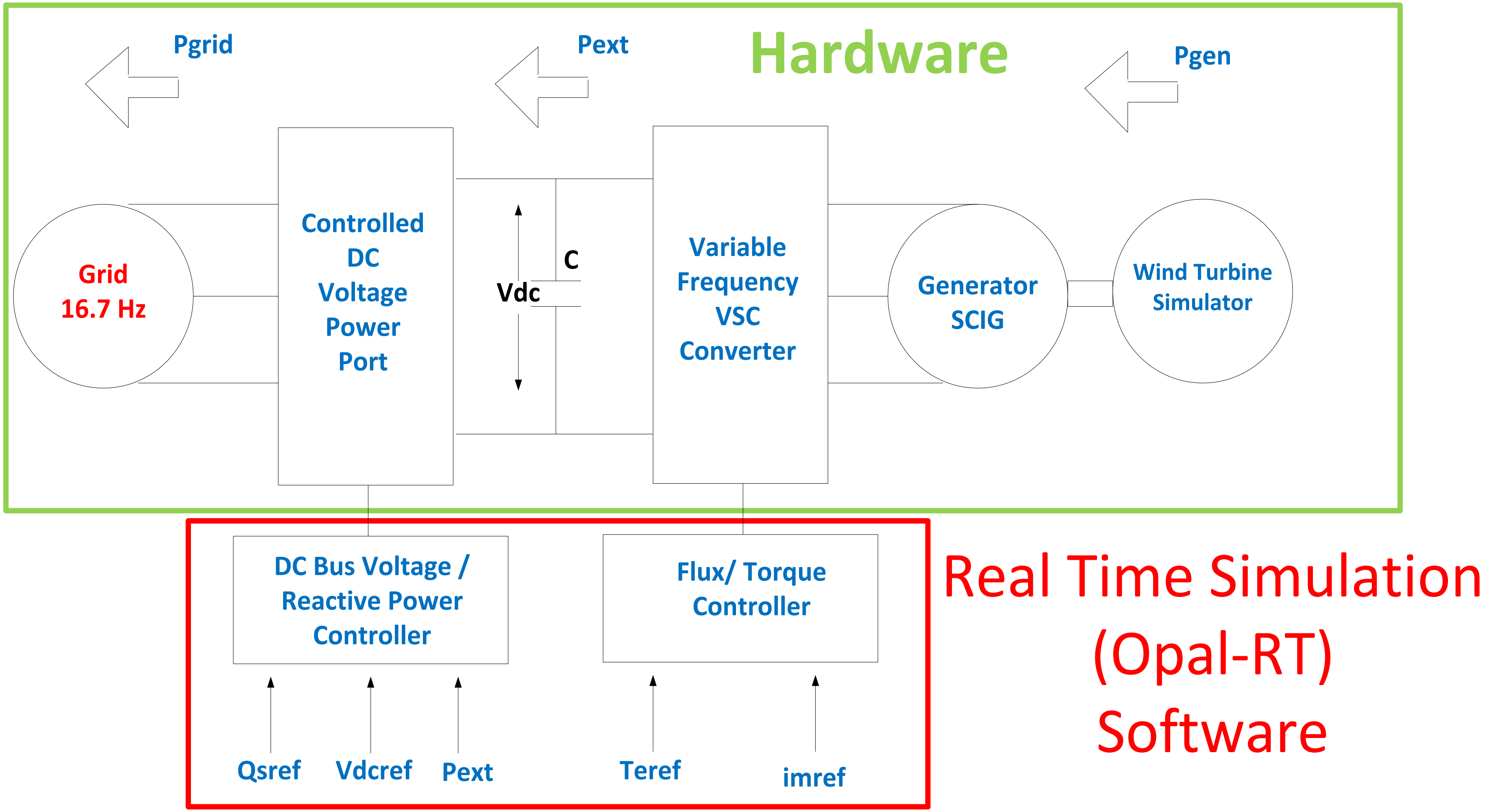
WT Connecting to an LFAC Grid

- Fixed speed and DFIG wind turbine configurations – larger generators to overcome start-up transients
- Full conversion WT – ability to reconfigure the converter to synchronise to the 16.7 Hz grid
- Design of the WT Trafo needs to be relocated on the platform or tower

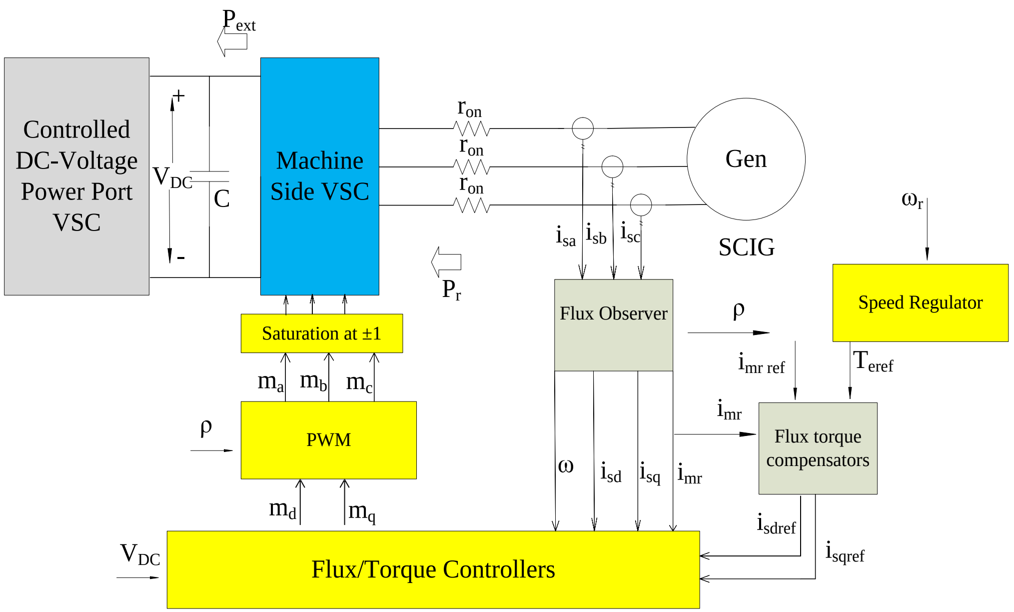
Overall LFAC Transmission System



Lab Setup


Hardware
Pgrid
Pext
Pgen
Grid
16.7 Hz
Controlled
DC
Voltage
Power
Port
Vdc
C
Variable
Frequency
VSC
Converter
Generator
SCIG
Wind Turbine
Simulator
DC Bus Voltage /
Reactive Power
Controller
Flux/ Torque
Controller
Qsref
Vdcref
Pext
Teref
imref
Real Time Simulation
(Opal-RT)
Software

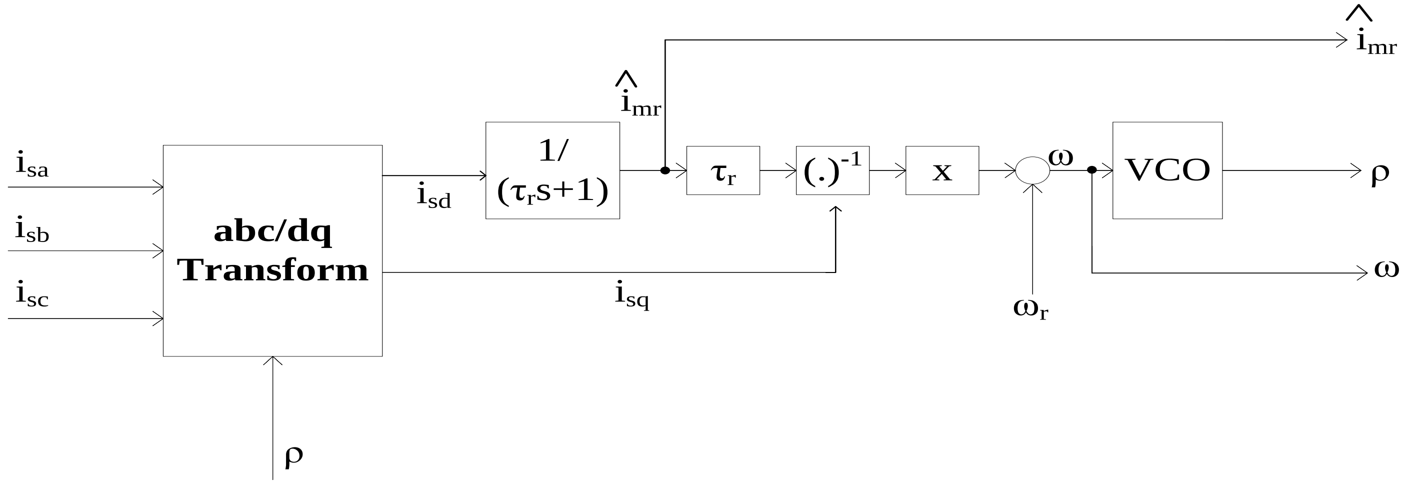
Generator Side VSC Control



- VSC control maintains a ($T_e\ \alpha\ \omega^2{}_r$) relationship for the generator so that MPPT (Maximum Power Point Tracking) is guaranteed
- The VSC can set both stator frequency of the generator to control speed and also stator current i_s to control the electrical torque T_e

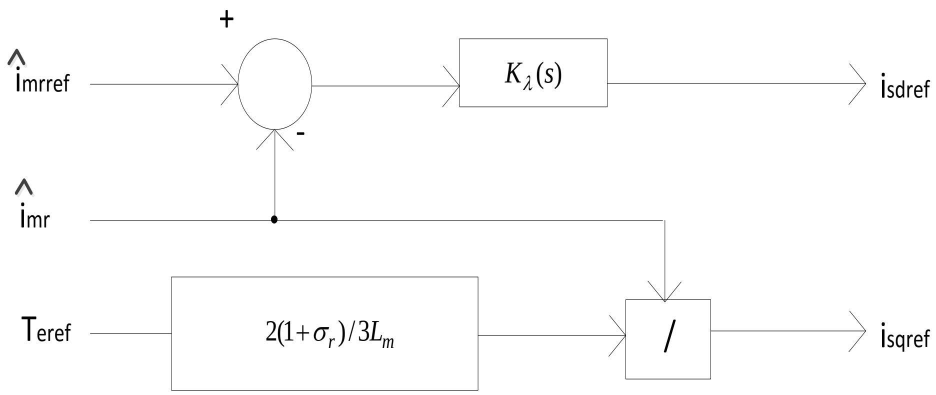
$$T_e = \frac{3}{2}\frac{L_m}{1+\sigma_r}\hat{i}_{mr} i_{sq}$$

Generator Side Flux Observer



- Torque control maintains i_{mr} (magnetising current) **constant** to a fixed value while using i_{sq} to set T_e
- A flux observer is used to estimate the magnetising current i_{mr}

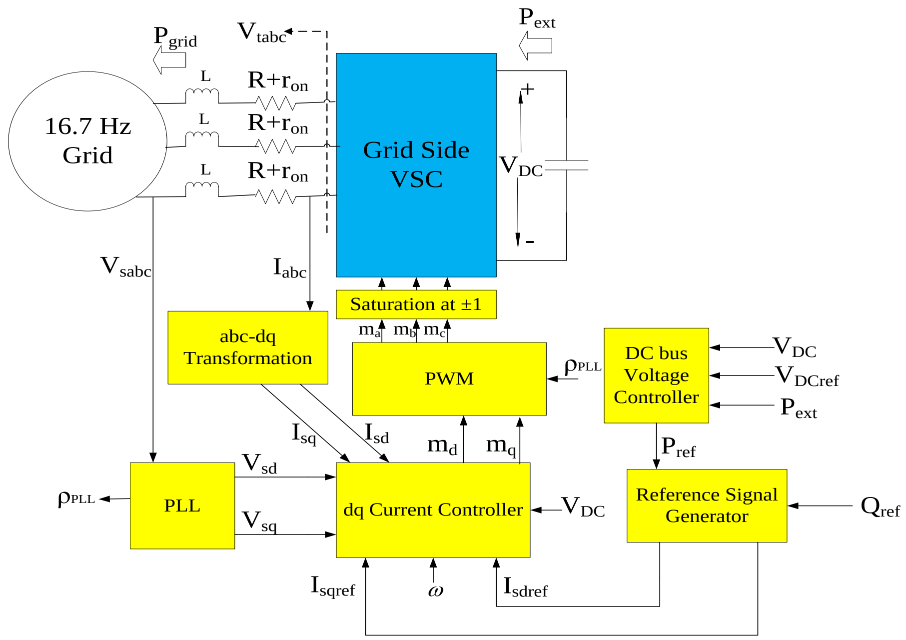
Flux/Torque Compensator



- The flux/torque compensator block receives a reference value for the magnetizing current reference i_{mrref} and an electrical torque reference T_{eref} as inputs and then outputs reference values for the stator d and q currents, i_{sdref} and i_{sqref} which in turn serve as inputs to the inner *dq* current controller

$$\hat{i}_{mrref} = \sqrt{\frac{2}{3}} \frac{V_{sn}}{(1+\sigma_s)L_m \omega_0}$$

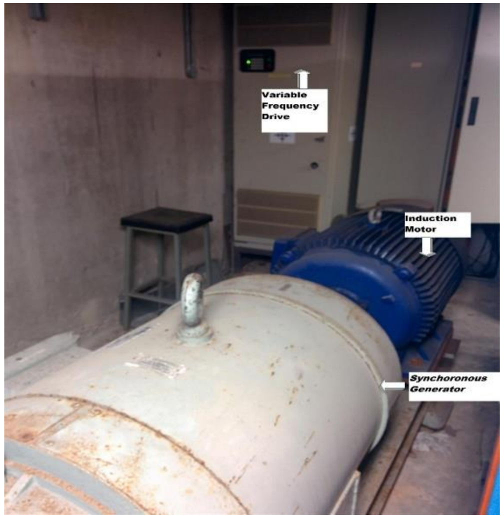
Grid Side VSC Control



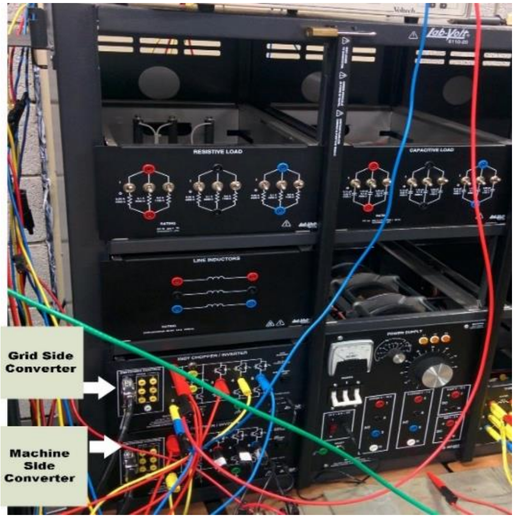
- PLL is utilized to synchronize the converter with the offshore 16.7 Hz grid
- The DC bus voltage controller maintains a constant DC-link voltage

Pictures of the Actual Setup

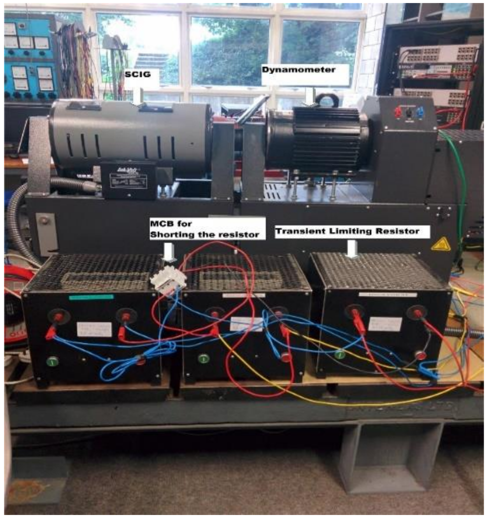
MG SET 16.7 Hz Grid



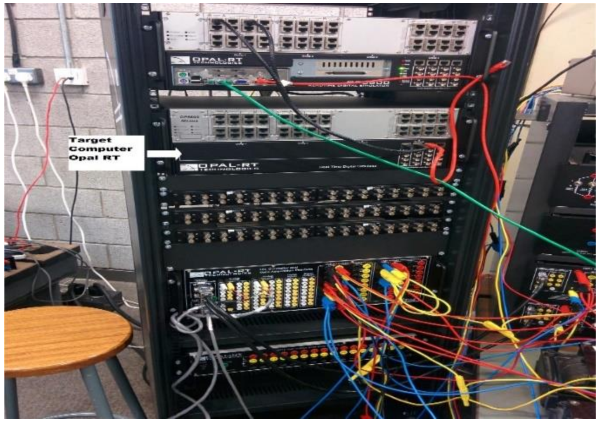
Back To Back VSC Converter



SCIG-Dynamometer Set



Opal-RT Real Time Simulator Control (Software)

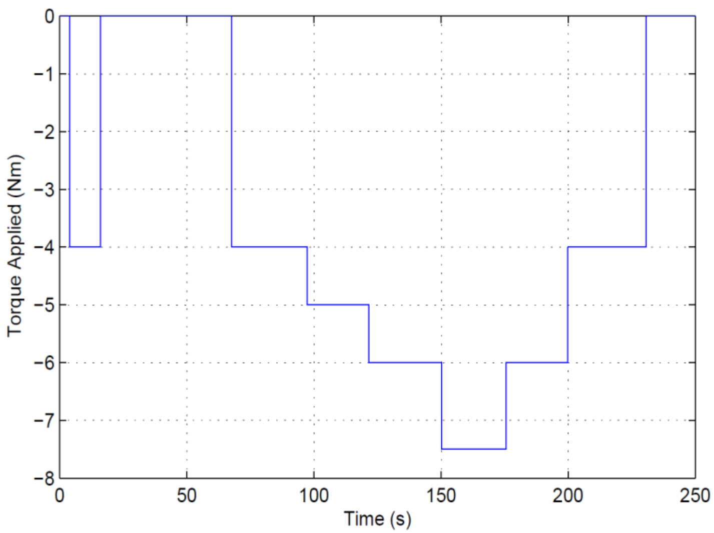


Test Procedure

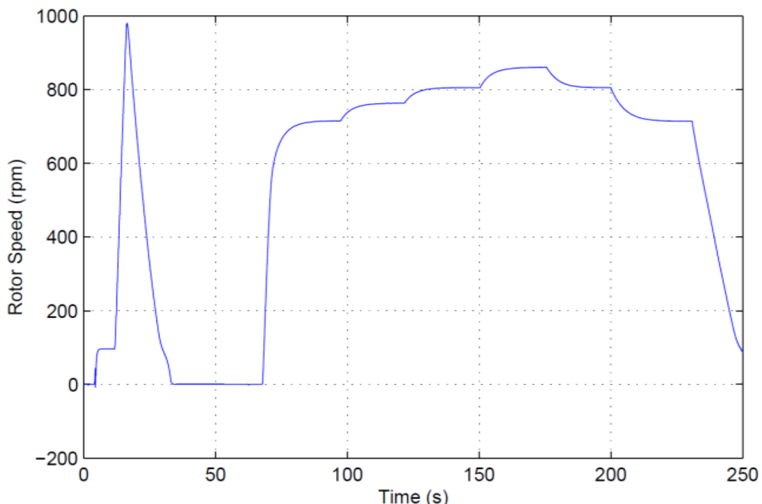
Generator Side

Grid Side

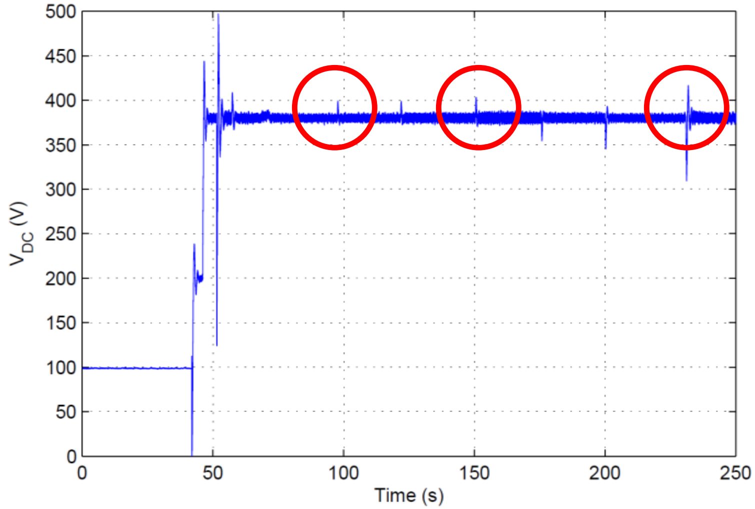
Applied Torque Measured



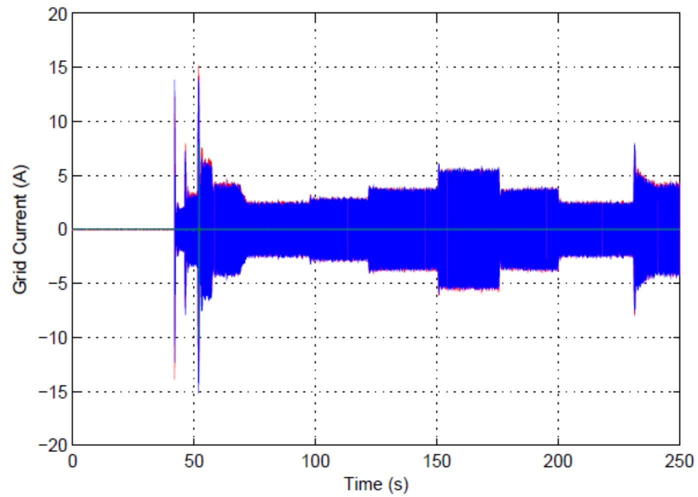
Rotor Speed Measured

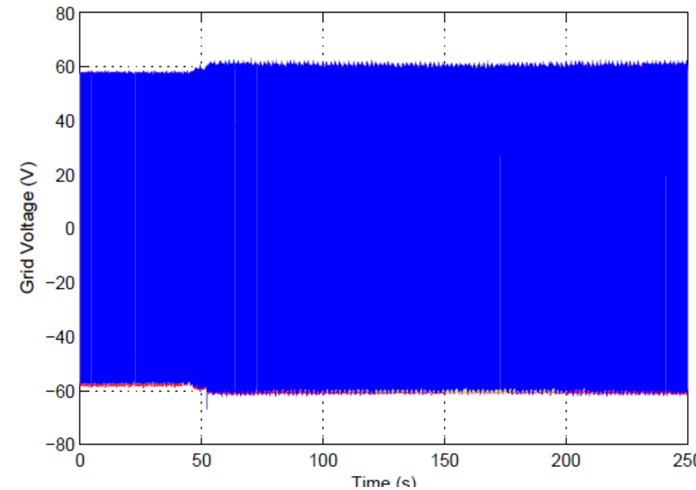


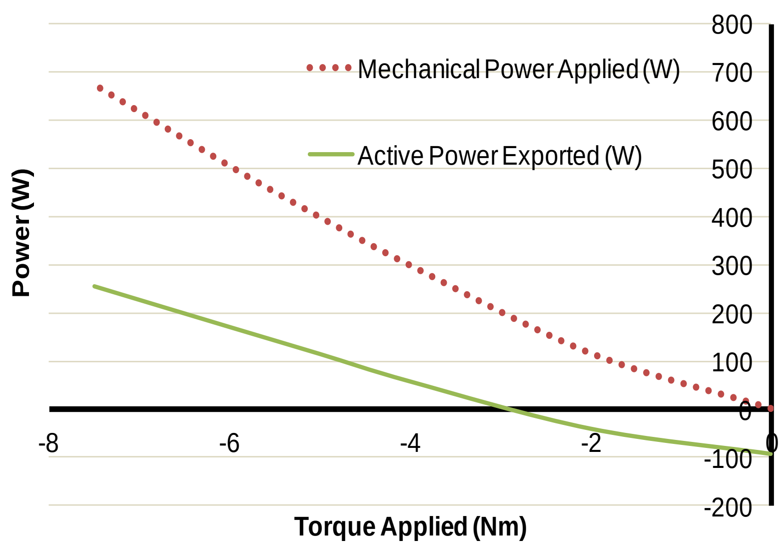
DC voltage Grid Side Converter Measured

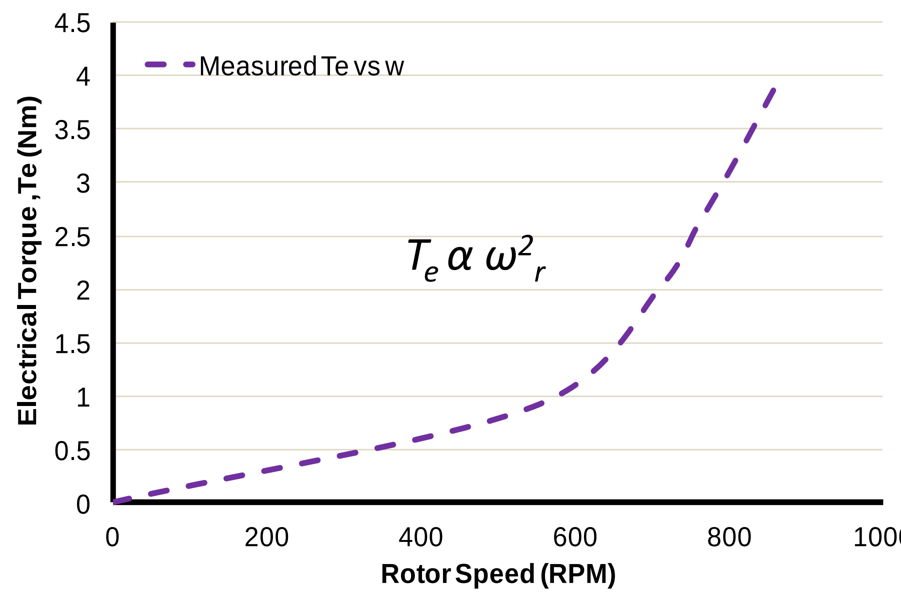


Measured Power Export Test

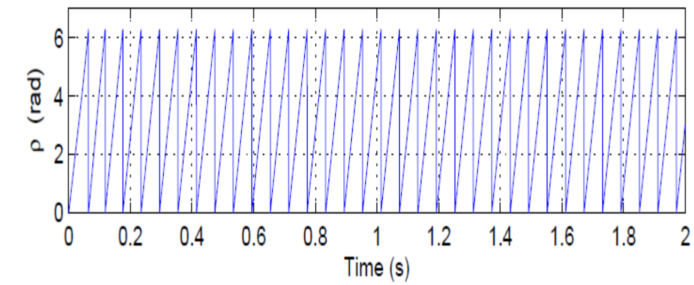


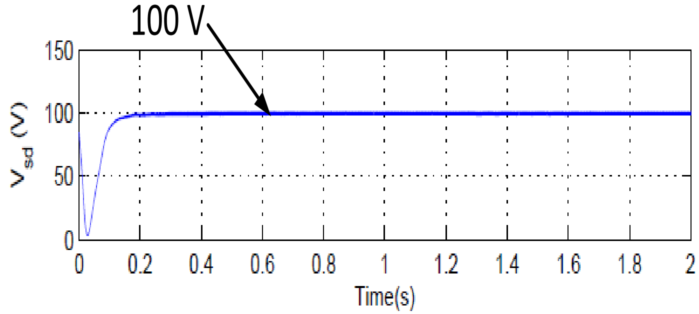


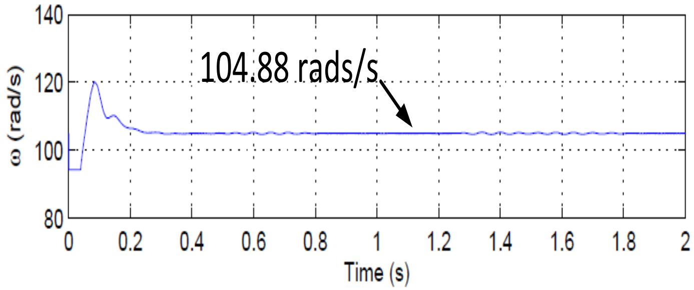


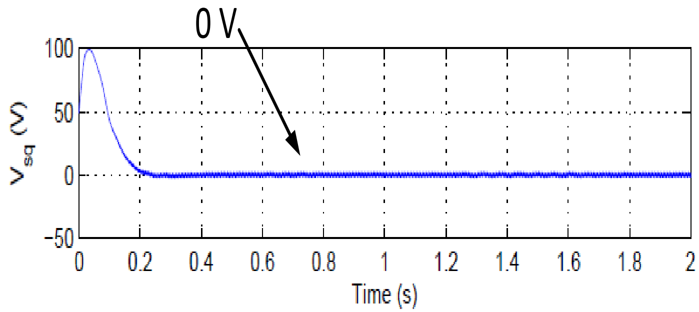


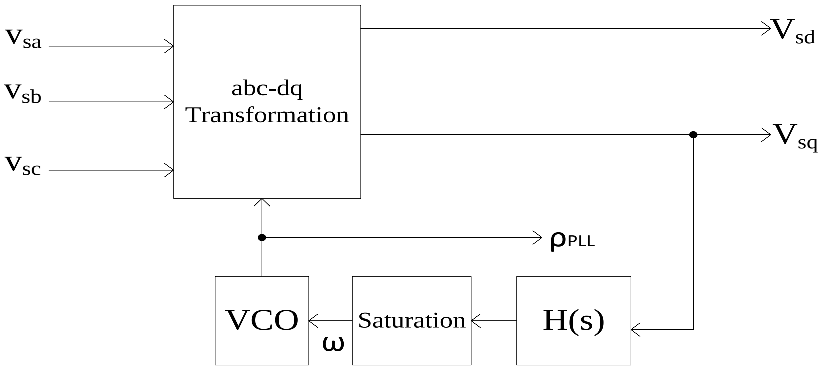
Grid -Side Phase Lock Loop at 16.7 Hz







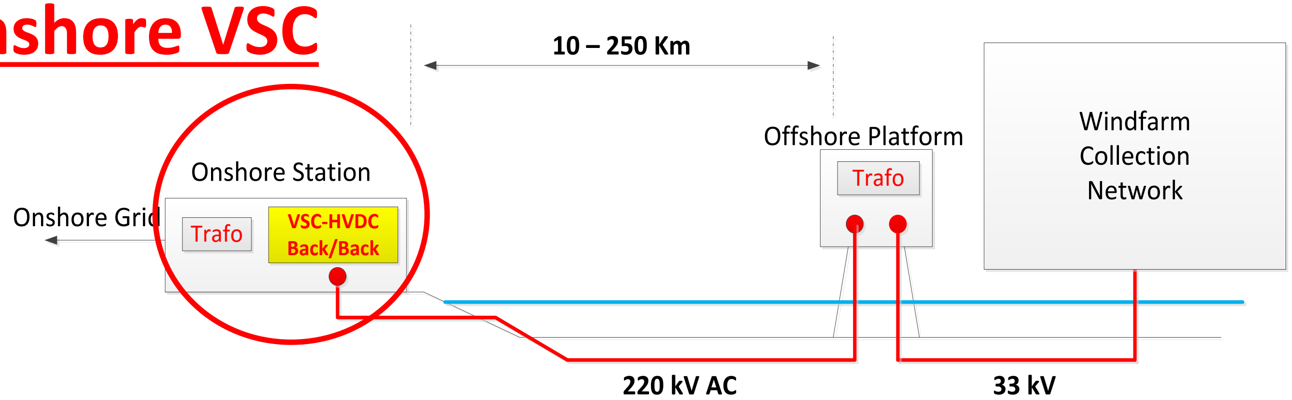




Next Steps

- Step 2 : Onshore VSC Back/Back step 16.7 Hz to 50 Hz

Step 2 Onshore VSC



- Poster covers this is detail :

Design and Modelling of a LFAC transmission system for offshore wind

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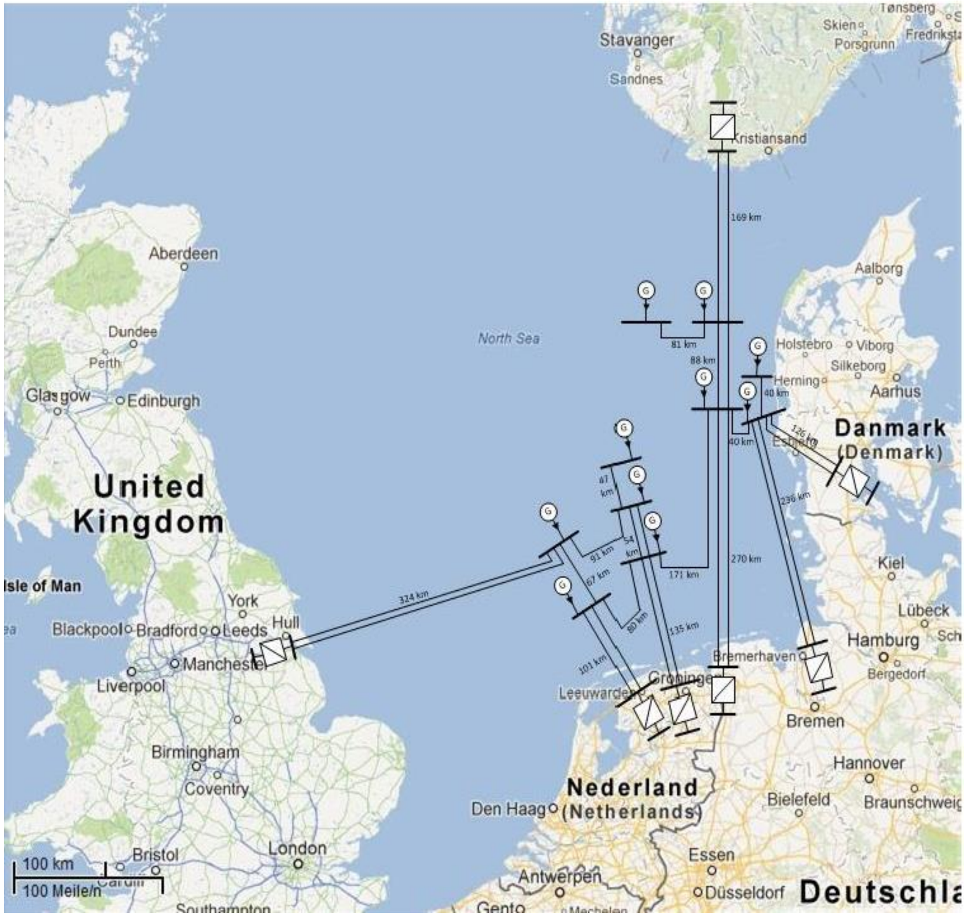
Other Work in Progress for LFAC

- <u>Transformer Optimisation 16.7 Hz</u>

  2 – 2.5 times the gross weight of a 50 Hz transformer for the same power

- Hypothetic Nord Sea Grid – *Istvan Erlich "16.7 Hz – The Missing Link"* **Meshed North Sea Grid**



Review

- LFAC is a real alternative to VSC-HVDC
- Demonstrated an operational LFAC connected WT
- Build the onshore BtB converter in hardware
- Evaluate the system under grid connection conditions

Acknowledgements

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Thank You

Questions?