Introducing the PFEC: A Novel Solution to Enable Low-Frequency AC Connections for Offshore Wind

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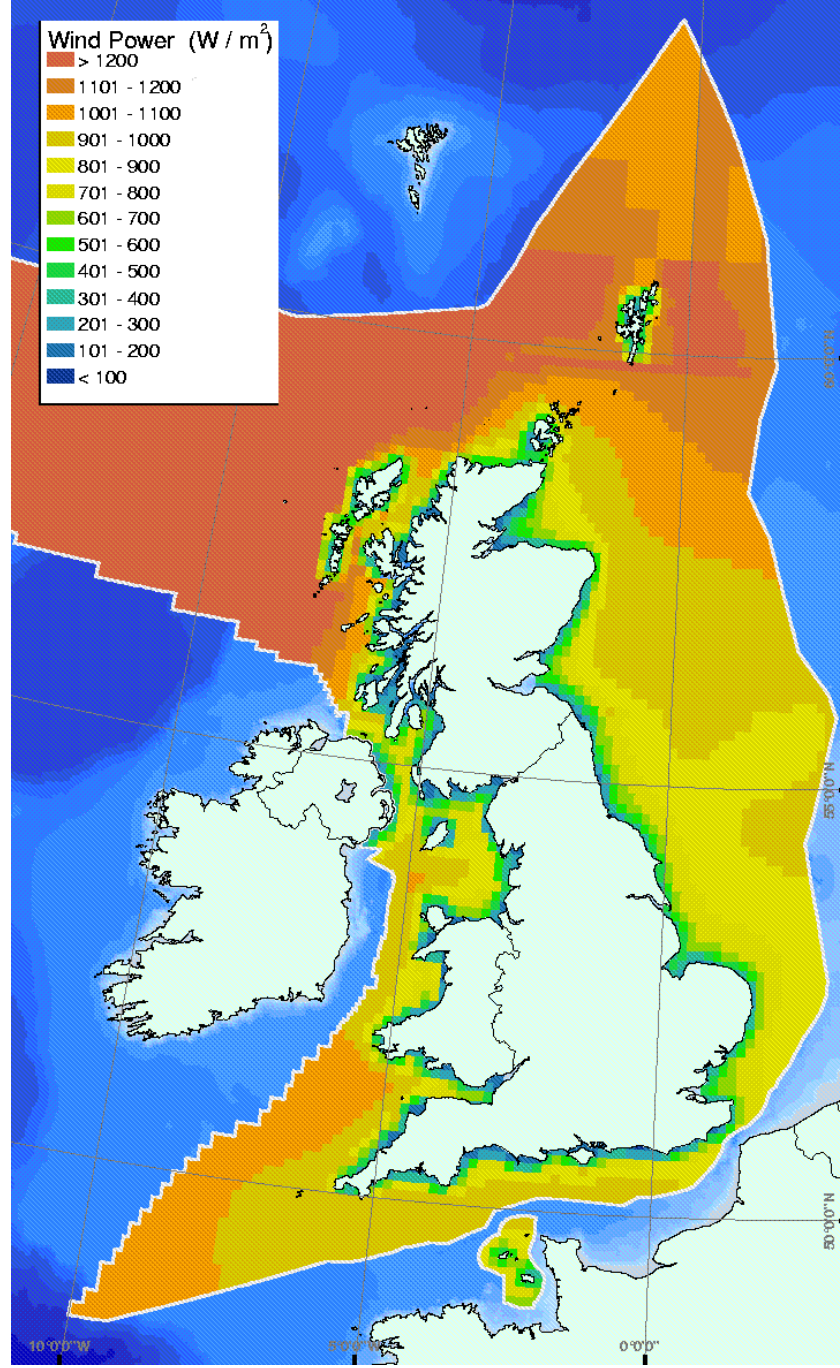
Background – Wind Resource

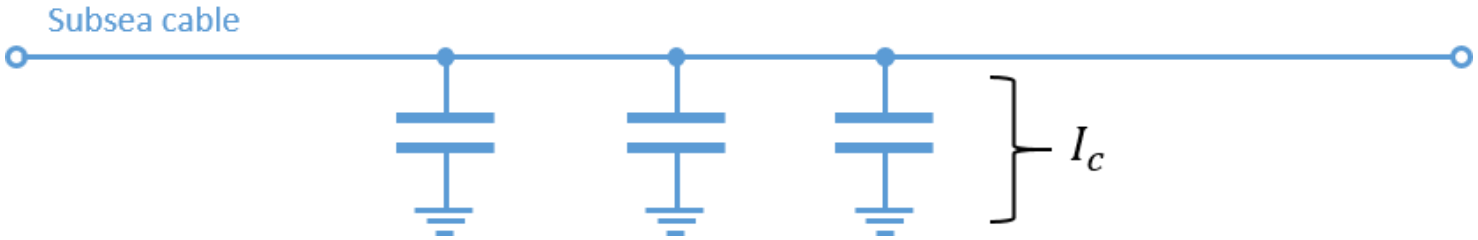
- Winds are stronger and more reliable out at sea
- The farther the distance offshore, the more consistent the winds become
- Wind farm developers will continue to move farther offshore to capture this improved resource



Atlas of UK Marine Renewable Energy Resources – The Crown Estate

Background - Cables

- As we move further offshore, charging currents in the cable become a problem for HVAC transmission, forcing us to seek an alternative



- HVDC is seen by many as the solution to this problem, but it is extremely complicated and still contains many unknowns

- LFAC sits between these two options, offering a solution for medium-range wind farms

Problems with HVDC

Problems with HVDC
New technology
Limited supply chain
Bespoke designs
Insufficient knowledge of cables
Difficulty locating and fixing faults
Converter weight (> 10000 tonnes)
Costly delays with recent projects
High risk premiums

SylWin1 – Siemens, TenneT

Low Frequency AC

- Charging currents are directly proportional to frequency

$$I_C \propto f$$

- Transmitting power at a lower frequency reduces I_C and increases the range of the cables
- Proposed designs for LFAC are power-electronics based

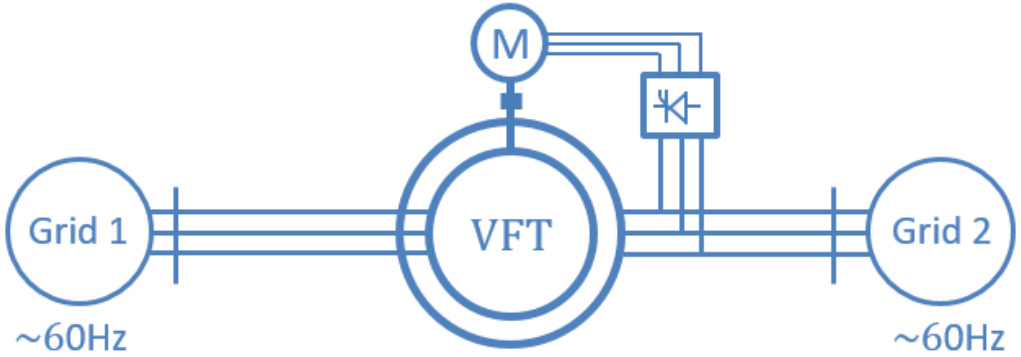
- The PFEC is not…

The Partial Frequency Energy Converter (PFEC)

- The PFEC exploits the principles of electromagnetism to provide an interconnection between two asynchronous networks
- Currently working with Strathclyde University to obtain the patent
- Further details are protected

Variable Frequency Transformers (VFT)

- The VFT naturally synchronises two asynchronous grids
- Rotor speed is proportional to the difference in frequency
- Several VFTs have been installed in North America



Variable Frequency Transformer, Laredo Texas – General Electric

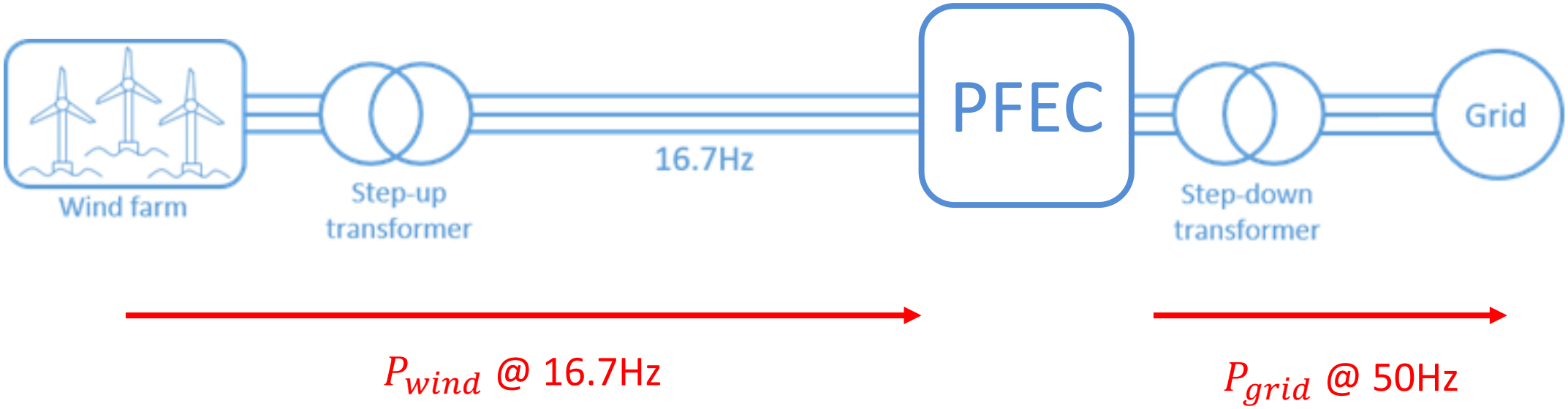
Features and Limitations

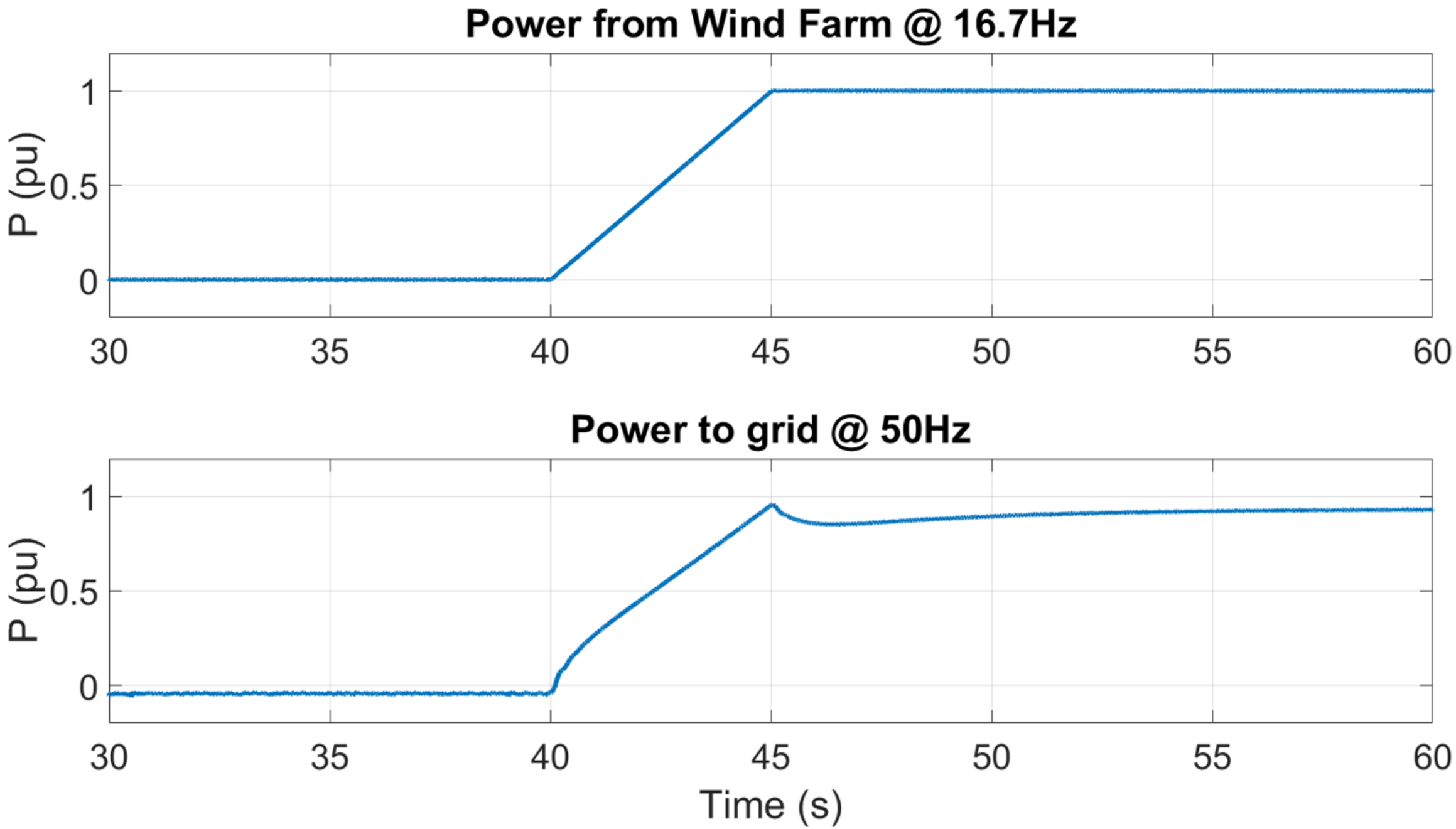
- The PFEC combines modern control techniques with robust generator technology bringing the advantages (and some disadvantages) of both

Features	Limitations
Longer transmission range	Limited power handling capacity
Based on mature technology	Expensive
Controllable reactive power flow	Lower efficiency
Improved fault handling	Danger of overvoltage
Stable without power electronics	Larger transformers / switchgear
Provides natural frequency response	Requires maintenance

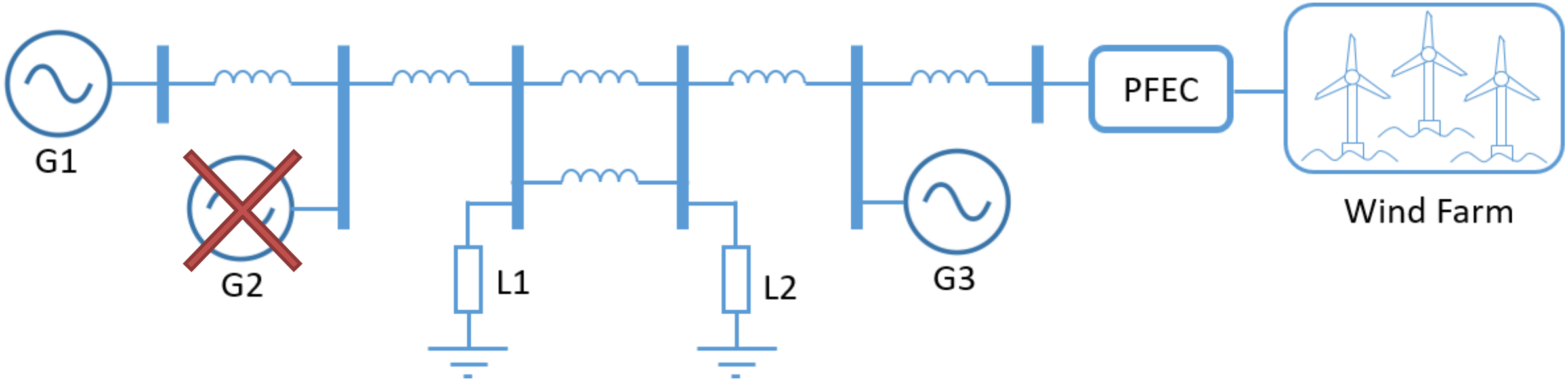
Simulation – Proof of Concept

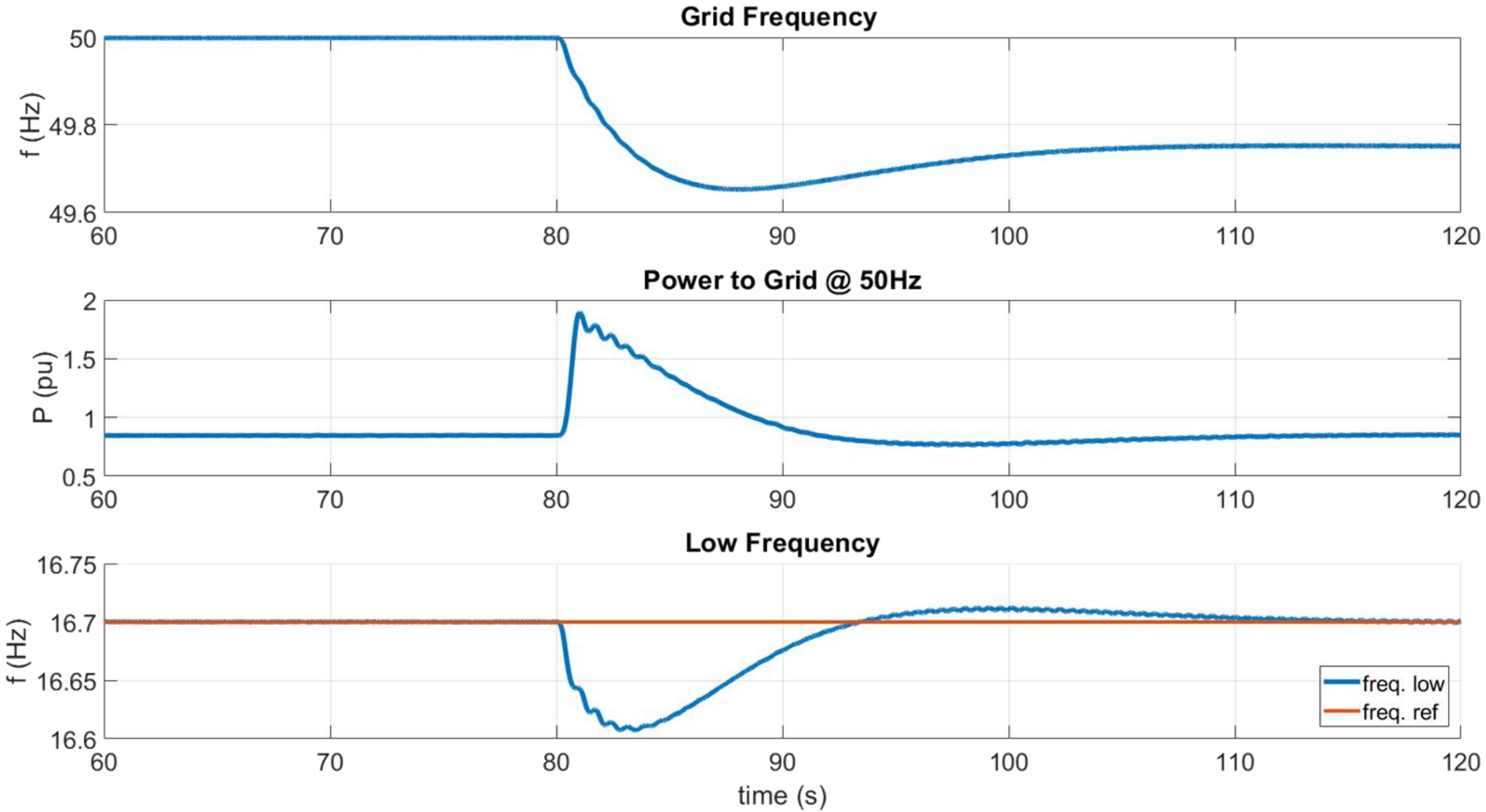
- Power is produced by wind farm at 16.7Hz
- Power arrives at PFEC and experiences a frequency conversion
- Power is delivered to grid at 50Hz



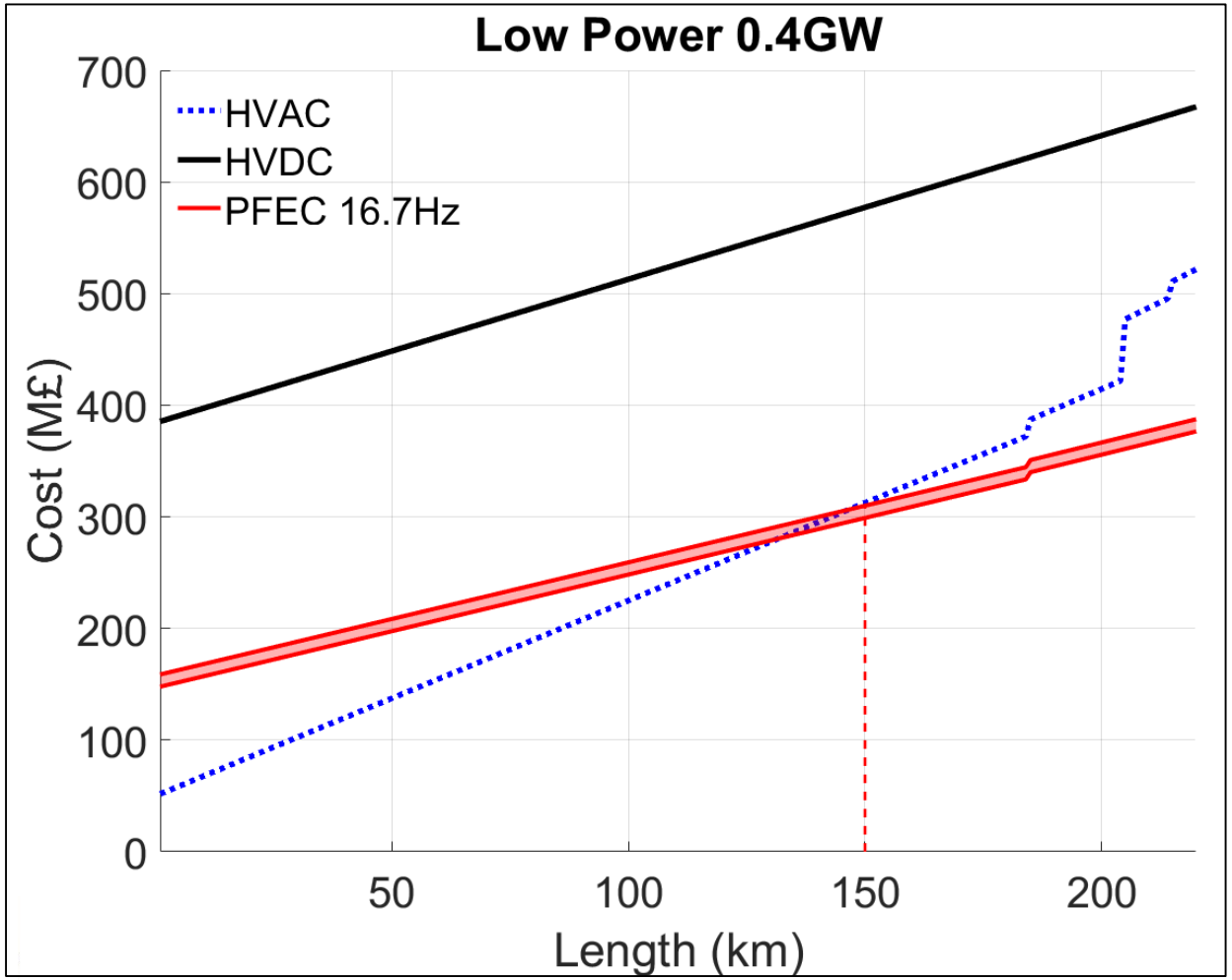

Power from Wind Farm @ 16.7Hz
P (pu)
1
0.5
0
30
35
40
45
50
55
60
Power to grid @ 50Hz
P (pu)
1
0.5
0
30
35
40
45
50
55
60
Time (s)

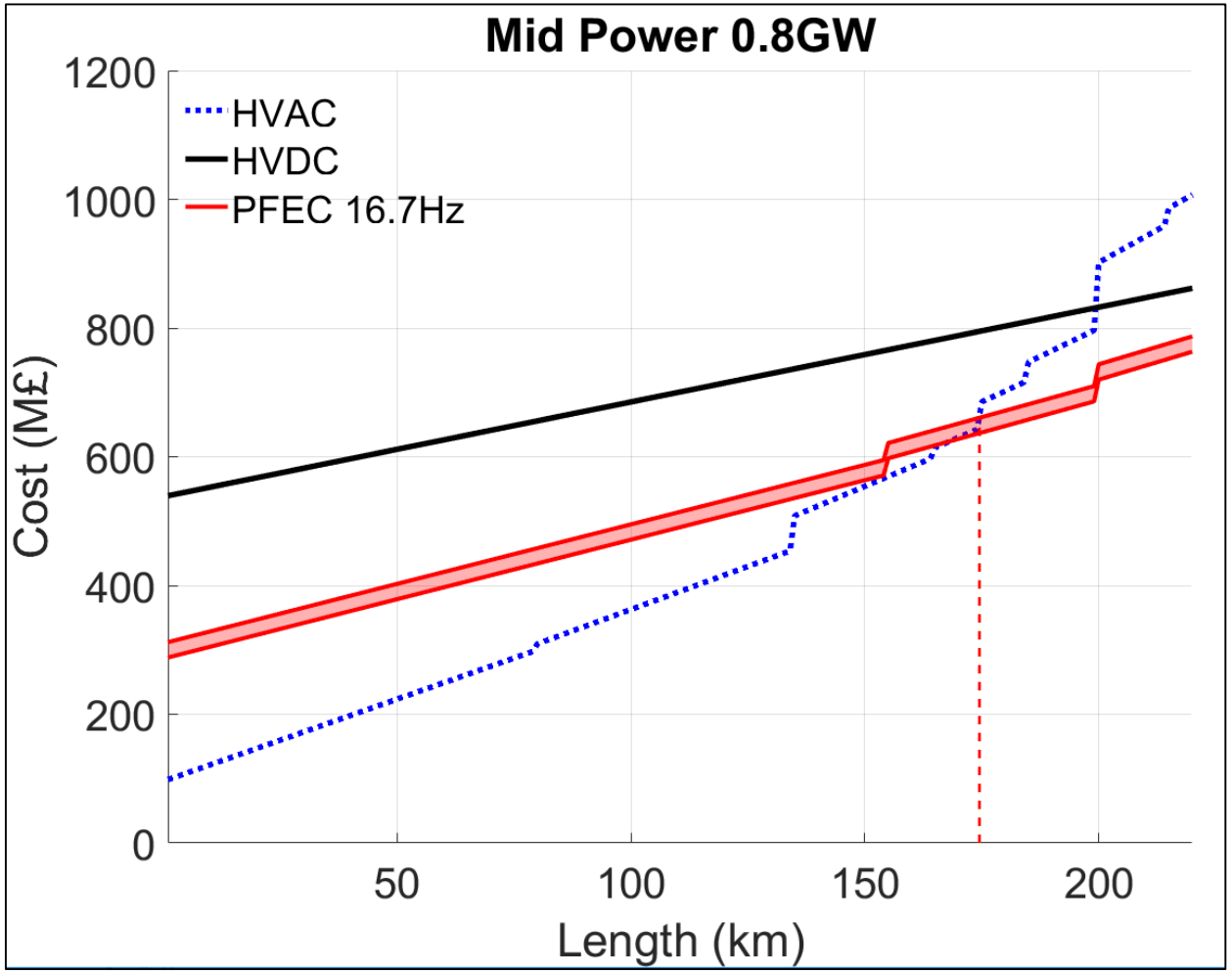
Simulation – Frequency Response



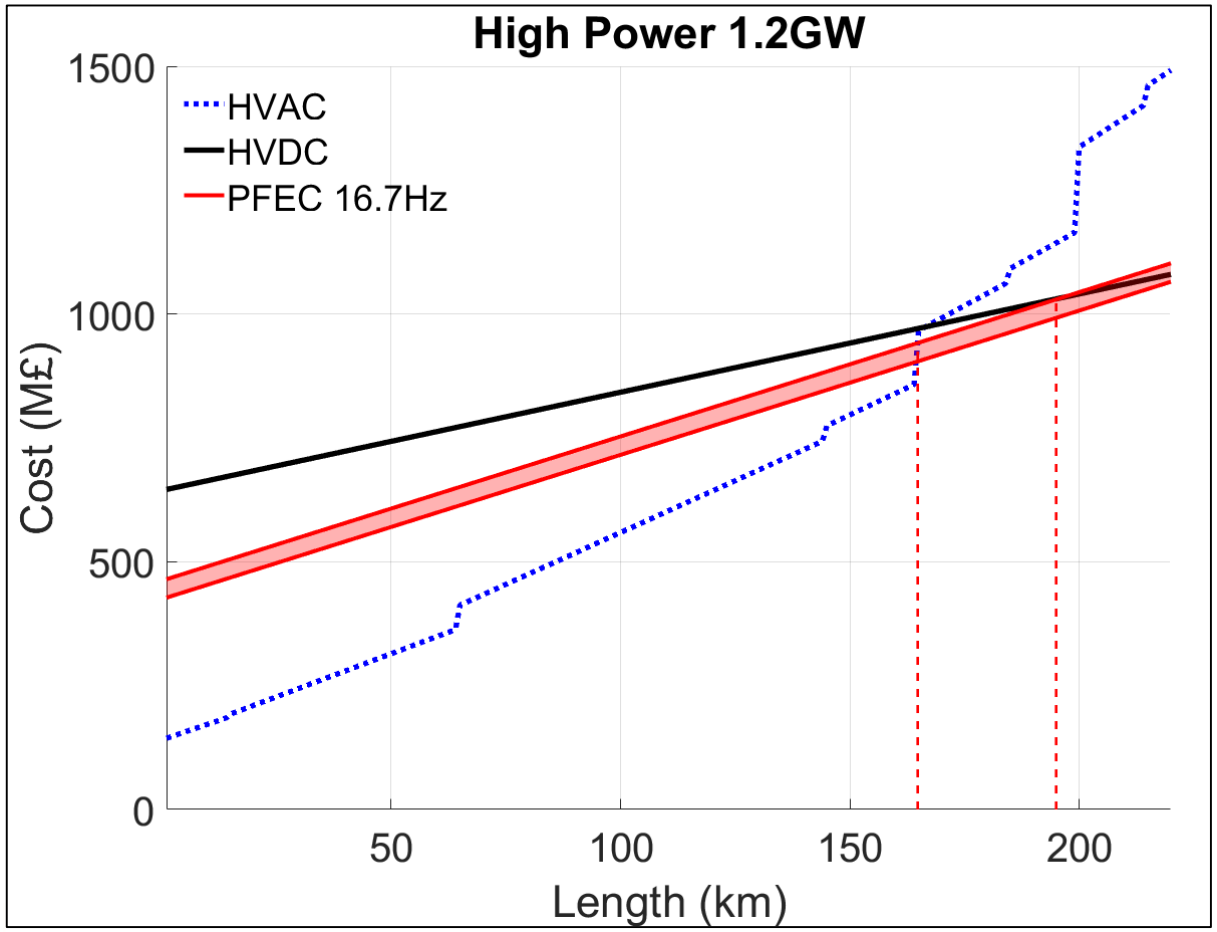

Grid Frequency
f (Hz)
50
49.8
49.6
60
70
80
90
100
110
120
Power to Grid @ 50Hz
P (pu)
2
1.5
1
0.5
60
70
80
90
100
110
120
Low Frequency
f (Hz)
16.75
16.7
16.65
16.6
60
70
80
90
100
110
120
time (s)
freq. low
freq. ref

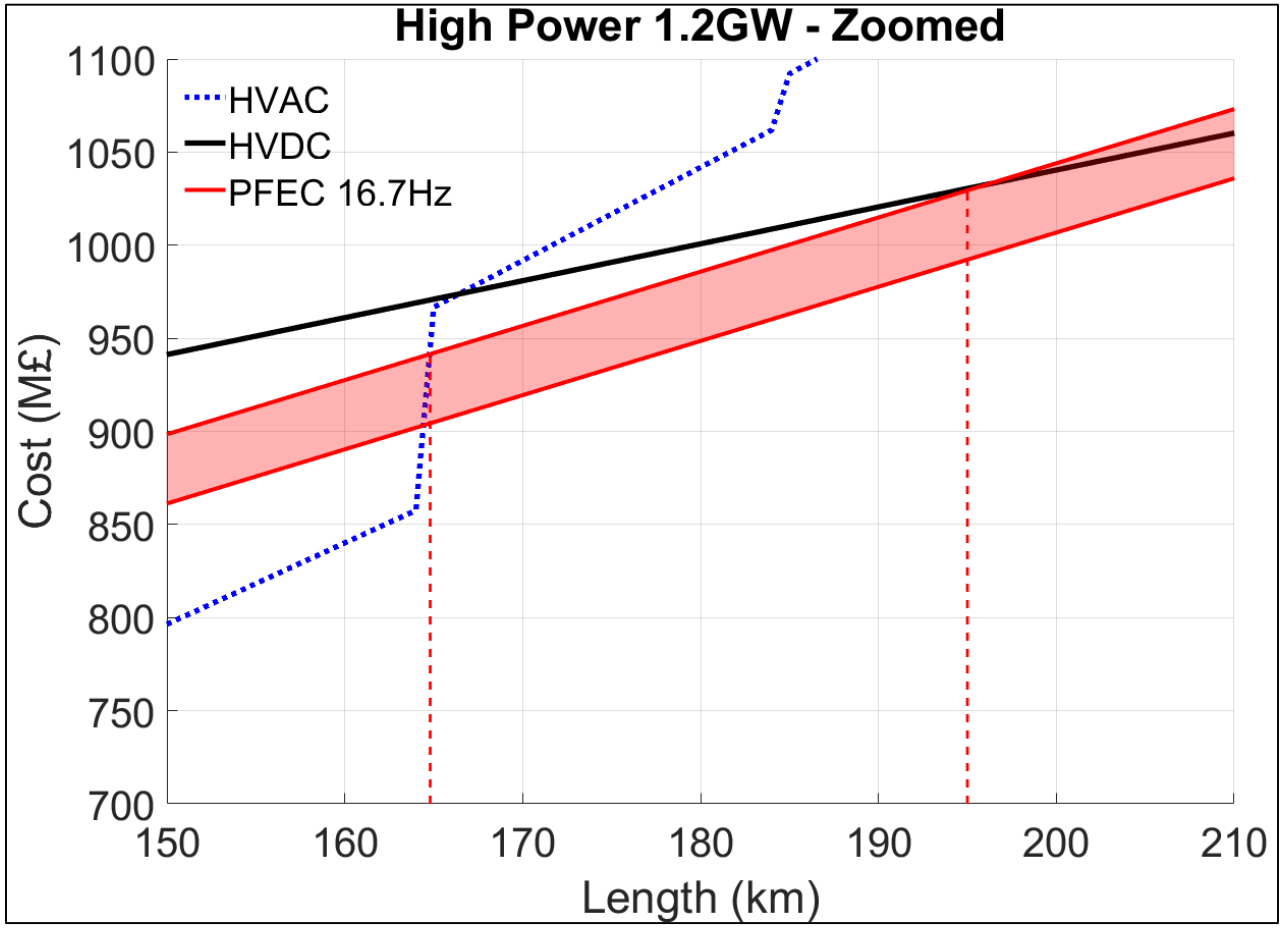
Economic Case – Low to Medium Power Scenario





Economic Case – High Power Scenario





Conclusions

- Low frequency AC connections are a potential option for modern offshore wind farms
- Results suggest that the PFEC is able to compete with HVAC and HVDC both in terms of functionality and cost
- Prototype is in development
- The concept of variable frequency may have far reaching consequences in the design of future power systems

Wind & Marine Energy Systems CDT

University of Strathclyde Glasgow

Thank you for your attention, any questions?

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