Multiphysics Modelling of Gaia-Wind Turbines

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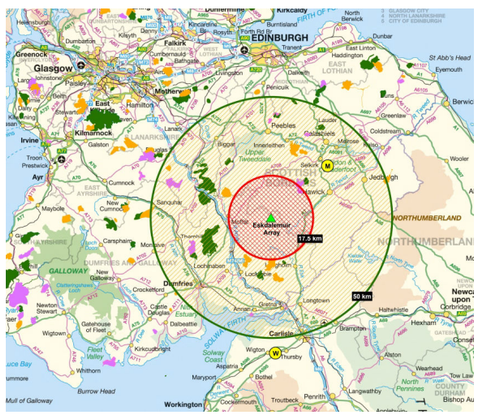
Introduction

Situated at Eskdalemuir, near Langholm, in the Scottish Borders, the Comprehensive Test Ban Treaty International Monitoring System monitors for all types of nuclear explosions; the site constitutes the UK's seismological contribution to the Treaty.

Previous Keele studies concluded that micro-seismic noise is propagated through the ground from large wind turbines, as the rotation of the blades excite resonant modes of the tower. These vibrations have the potential to adversely impact the detection capabilities of the Eskdalemuir array and limits were set on the permissible aggregate vibrations. As this limit is now approaching, the MOD has placed a ban on all new wind turbines within a 50km radius of the site, seriously impacting the deployment of both large and small turbines with over 2.5GW of new capacity on hold.



Exclusion zone at 17.5km (complete exclusion) and 50km (capped capacity)around the Eskdalemuir Array.

At the time, the terms of reference of the previous study did not consider small or medium wind turbines. As government policy actively encourages micro-generation schemes, a research project has been established at Keele University to investigate what steps can be taken to permit small-scale wind development, whilst maintaining the detection capabilities at Eskdalemuir. The project involves the modelling and monitoring of vibrations from a range of small wind turbines. This enables us to establish whether the same algorithms for calculating the micro-seismic noise level applicable to the large turbines can be appropriately applied to small systems. This is essential for future small and medium wind turbine developments in the area.

Gaia-Wind 133 lattice tower

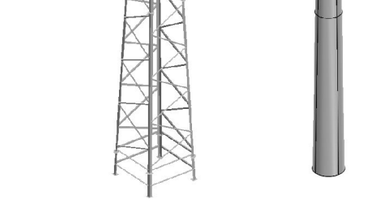
Two wind turbines are modelled here, both manufactured by Gaia-Wind. They both have the same nacelle (top section) and blades, but differ in the tower; one is tubular and the other lattice.

Modelling Methodology

Modelling is used to calculate the resonant frequencies of the tower. It can be useful to model the turbine prior to monitoring, so that key locations on turbine and off for placement of the accelerometers can be identified. The results from vibration monitoring of the turbines can be used to verify the models.

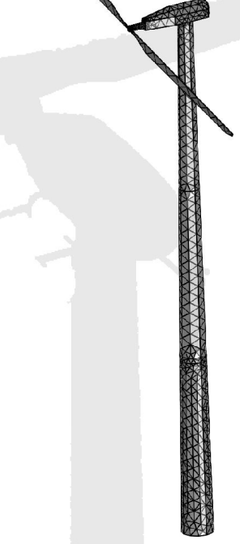
The key steps for modelling a turbine are as follows:

1. Generate a CAD (Computer Aided Design) model of the turbine. This is done in AutoCAD. The two respective towers are shown on the right.



CAD models of the lattice (left) and tubular (right) Gaia-Wind 133 turbines

2. The CAD model is imported into Comsol, a multiphysics modelling software package. The tubular tower is defined using shells and the lattice with 3D truss. Material conditions are assigned to the different sections of the turbines, eg the tower is steel.



Meshed tubular tower turbine

3. A tetrahedral and triangular mesh is applied to the tower. This provides the nodes on which the software can perform FEA (Finite Element Analysis).

4. FEA is performed on the meshed model. A eigenfrequency analysis allows the resonant frequencies of the tower to be visualised. The details of individual bending modes and amounts of stress and displacement can also be seen.

A frequency response analysis performs calculations over a range of frequencies to calculate properties like acceleration, velocity, total displacement and stress.

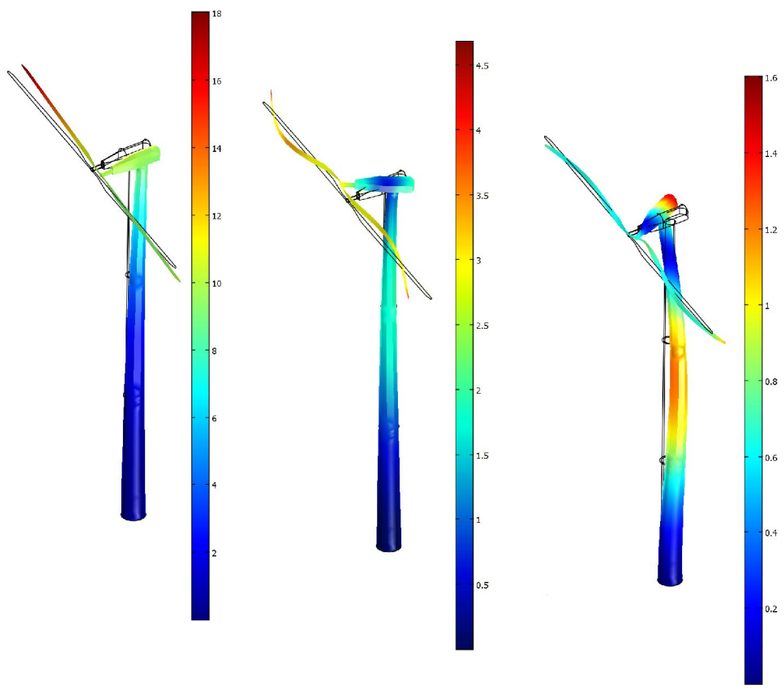
Results

An eigenfrequency analysis was performed on both models.

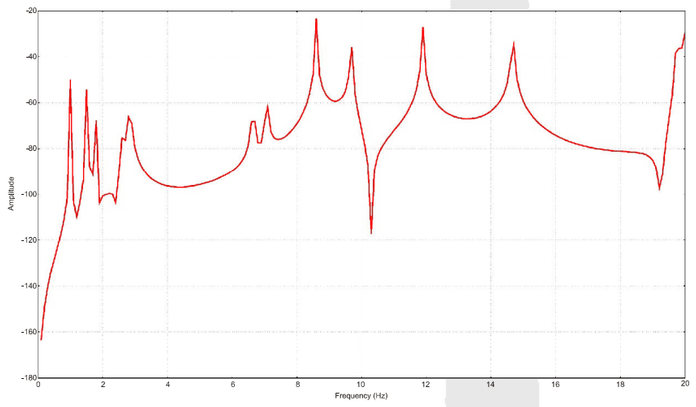
The tubular tower, although the amount of movement is very small (a few μm) the actually bending modes and twisting of the nacelle can be visualised

The tubular tower has the following resonant modes:

- First bending mode occurs at 1.5Hz and 1.8Hz
- Torsion of the nacelle occurs at 8.6Hz
- Second bending mode occurs at 9.7Hz and 11.9Hz



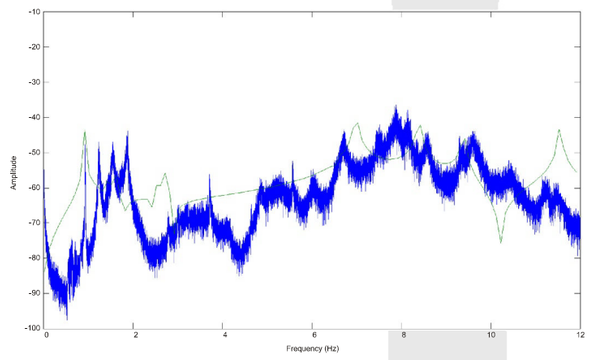
Three different resonant frequencies of the tubular tower. Left is the first bending mode, middle shows Torsion and right the second bending mode. The shading indicates displacement in μm with red high and blue low.



Frequency response analysis of the tubular tower.

Frequency response analyses are you used to calculate properties of the model over a range of frequencies, similar to a spectrum.

For each tower, calculations were performed over a frequency range from 0 to 20Hz at 0.1Hz intervals. The graphs above and right are the results for the tubular and lattice towers respectively. The plots show the amplitude of the acceleration signal in the y-direction at a location on the tower near to the base, equivalent to where accelerometers would be positioned when monitoring.

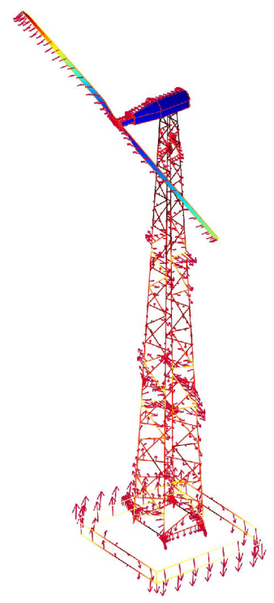


Frequency response analysis comparison of the monitored (blue) and modelled (green) data for the tubular tower. Accelerometers and points data are gathered at 0.8m from the ground.

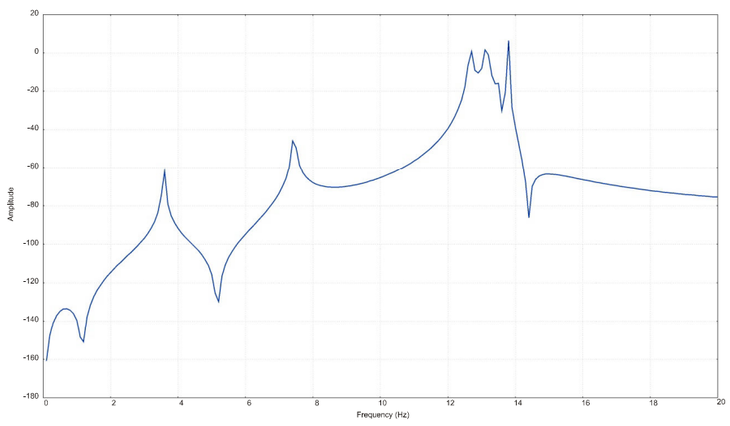
The resonant frequencies of the lattice tower are not simple to visualise due to the structure. The image on the right shows one of the bending modes of the tower. The arrows and shading are proportional to the amount of displacement; red is high displacement and blue is low.

The lattice tower has the following resonant modes:

- Bending modes occur at 6.2Hz and 6.4Hz.
- Torsion of the nacelle occurs at 22.2Hz
- Other Bending modes occur at 28Hz and 29.4Hz



Bending mode of the lattice tower. Arrows indicate direction and amount of displacement.

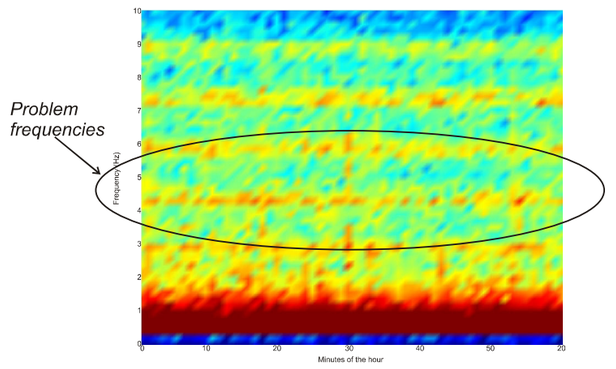


Frequency response analysis of the lattice tower.

Summary

- Multiphysics modelling of wind turbines enables the resonant frequencies to be identified and visualised.
- Due to approximations in models and damping in the real world, the frequency response from the model will never match the power spectra created from the actual data exactly.
- The model of the Gaia-Wind turbine are a good representation of the actual structure.
- The problem frequencies of 4-6Hz previously identified as being generated by the large wind turbines (see spectrogram to right) are not present on either of the Gaia turbines.

Gaia-Wind 133 tubular tower



Spectrogram of a 60m Nordex turbine. Red indicates levels of high amplitude and blue low amplitude.

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