1. Monitoring Wind Turbine Noise

Development of wind-generated energy is pursued by multiple signatory States of the Comprehensive Nuclear Test Ban Treaty as a renewable alternative to traditional methods of energy generation (coal, gas, nuclear). In Canada, wind power capacity has increased by approximately 400% over the last two decades from a nationwide capacity of just 23 MW in 1997 to more than 9,219 MW by the end of 2014 (CanWEA, 2014).

As wind power generation facilities increase in size and number, encroachment upon International Monitoring System (IMS) stations can occur, since remote sites that provide quiet background conditions for seismic monitoring, may also be desirable for wind turbines. Such has been the case at AS104 in Eskdalemuir, Scotland (Styles et al. 2005). In such instances, infrasonic and/or infrasonic emissions of the turbines become an undesirable source of noise within the monitoring frequency band.

In 2013-14, in cooperation with Health Canada, a monitoring study was conducted to identify and characterize the noise of megawatt wind turbine facilities and possible linkages to human health factors (Michaud et al., 2013). As part of this study, the seismic and infrasonic noise of a 12 MW wind facility near the City of Summerside, Prince Edward Island, Canada was passively recorded by four temporary seismo-acoustic monitoring stations (Fig. 1). The facility consisted of four Vestas 3.0MW V90 wind turbines.

Analysis of the seismic data seeks to identify, characterize and explore the behaviour of the turbine noise to determine the extent of the noise contaminant and estimate the separation required to safeguard hypothetical monitoring stations from such facility.

2. Seismo-acoustic Monitoring Stations

The temporary seismo-acoustic stations used in the study were designed to be power independent, low maintenance and non-intrusive platforms to passively record the ambient infrasonic sound and local ground motions simultaneously at increasing distances from the Summerside wind turbine facility. Each station consisted of three main components: (i) a solar power and communications component, (ii) an instrument vault and (iii) a porous hose spatial filter (Fig. 2). The instrument vault consisted of a half buried High Density Polyethylene (HDPE) pipe with a concrete base. The seismometer, a Nanometrics Trillium 1209P, was situated at the base of the vault, while a Chaparral Physics M25 microbarometer was installed on a small shelf above the seismometer. The microbarometer was then connected to an external 30 m diameter, four-armed, porous hose spatial filter. The instruments were selected to provide an overlapping flat response between 0.1 – 100 Hz.

6. Safe Distances for Monitoring Stations

To determine a safe distance for a hypothetical monitoring station from the Summerside facility, the spectral growth and attenuation model for the most dominant 3BP and 28M peaks are compared to regional seismic noise background levels as a function of wind speed (Fig. 5). With a condition that amplitudes of these peaks must be less than or equal to the background, a curve of minimum safe distances as a function of wind speed can be produced. In this specific case, a minimum separation distance of ~63 km is advised for a station to avoid recording the facilities turbine noise.

5. Comparison to Human Perception Thresholds

While seismic noise generated by the Summerside wind turbines is observable by sensitive seismic instruments, and undesirable for scientific measurements, a significant question that arises is whether this noise may also be perceivable by the average person during daily life. To address this question, the turbine noise spectra observed by the four monitoring stations during the windiest conditions (when noise levels were at their peaks) are compared to amalgamated measurements of whole-body human vibration perception thresholds (Griﬃth, 1990). At these levels and greater, vibration becomes noticeable by the human body (Fig. 6). In comparison, the most prominent and furthest observable turbine seismic noise at 3BP and 28M frequencies are approximately 100x below human perception threshold, while the entire seismic background is at least 200x below perception levels. Thus it is highly unlikely that this turbine-generated seismic noise would be perceivable by even the most sensitive of persons.

References

1. Growth and Attenuation of Seismic Noise

Growth of the spectral peaks seen in the seismic data (Fig. 3) was hypothesised to relate to the power output of the turbines. As the turbines respond to increasing winds, the more frequently the blades pass the tower and the higher the pressure between the tower and blades become, resulting in greater forces to bend the tower. As the tower flexes and twists, these motions are transmitted via the tower’s foundation. Fitting the shape of the V-90 power curve to the measured spectral growth, an excellent correspondence is observed (Fig. 4a).

To determine the attenuation of the turbine induced ground motion, spectral peak measurements as a function of distance are compared to body and surface wave attenuation curves (Fig. 4b). The turbine-induced ground motion attenuation curve is consistent with surface waves propagating to the local bedrock with a high quality factor. This is consistent with previous observations of smaller turbines (e.g. Styles et al. 2005, Schoﬁeld, 2002). Following Bowers (2013), the turbine noise power spectrum of the wind farm, PS, as a function of frequency and distance, r, from the turbine may be expressed in the form:

\[ P(f, r) = \frac{A}{(2\pi f)^3} \left( \frac{1}{r^2} \right) \exp \left( -\frac{c}{(2\pi f)^{2/3} r^{2/3}} \right) \]

with \( a = 0.5 \) and a large value \( v_0 = 2400 \) representing only minor anelastic absorption of surface waves within the local sandstone bedrock, and where \( f \) is the turbine noise spectrum with a reference distance, \( r_o \).

3. Characteristics of the Turbine Noise

Data from the 10 m meteorological station at HC2P were used to extrapolate the winds at the turbine nacelle height of 80m using a standard wind shear power-law scaling with a shear exponent of 0.22 (Eqn. 1).

\[ U = U_0 \left( \frac{z}{z_0} \right)^{0.22} \]

Data windows of 10 minutes duration were then binned into 1 m/s wind speed categories. The spectra of these data segments were then stacked and an inner-quartile mean (IQR) taken following the procedure of Bowers (2013). These IQR spectra show that infrasonic and seismic noise of the four 3.0 MW turbines is restricted to ~0.5 – 10 Hz range, and consists of numerous spectral peaks (Fig. 3). In infrasound, the harmonic peaks are associated with the frequency of turbine blade passage (BP) in front of the turbine tower, consistent with the 3.0MW V90 turbine blades which rotate between 9.9 – 16.1 RPM (Vestas 2006). Within the seismic data, similar BP harmonics are seen, as well as peaks associated with bending (BM) and twisting (TM) modes of the turbine tower (Nuta et al. 2011). All these peaks are then observed to attenuate with increasing distance from the turbines. Measurements of the growth and attenuation of these peaks are used to constrain an analytical model for the turbine noise.

Fig. 3: Spectra as a function of wind speed at increasing distances from the turbines. Note the differences between BP harmonics seen in the infrasound and seismic spectra at HC2P. Also note structural modes are not observed infrasonically.

6. Seismic Sources in Theory and Practice