CHAPTER 20

Wind turbine noise measurements and abatement methods

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This chapter presents an overview of the types, the measurements and the potential acoustic solutions for the noise emitted from wind turbines. It describes the frequency and the acoustic signature of the sound waves generated by the rotating blades and explains how they propagate in the atmosphere. In addition, the available noise measurement techniques are being presented with special focus on the technical challenges that may occur in the measurement process. Finally, a discussion on the noise treatment methods from wind turbines referring to a range of the existing abatement methods is being presented.

1 Introduction

Wind turbines generate two types of noise: aerodynamic and mechanical. A turbine’s sound power is the combined power of both. Aerodynamic noise is generated by the blades passing through the air. The power of aerodynamic noise is related to the ratio of the blade tip speed to wind speed. The mechanical noise is associated with the relevant motion between the various parts inside the nacelle. The compartments move or rotate in order to convert kinetic energy to electricity with the expense of generating sound waves and vibration which is transmitted through the structural parts of the turbine.

Depending on the turbine model and the wind speed, the aerodynamic noise may seem like buzzing, whooshing, pulsing, and even sizzling. Downwind turbines with their blades downwind of the tower cause impulsive noise which can travel far and become very annoying for people. The low frequency noise generated from a wind turbine is primarily the result of the interaction of the aerodynamic lift on the blades and the atmospheric turbulence in the wind. High frequency noise is also generated due to the interaction of the air turbulence and the blades during their rotation, constantly changing angle of attack.
Depending on the rotational speed of the turbine, the size and the airflow wind turbines emit infrasound, low and high frequency sound waves. Large wind turbines produce infrasound of 8–12 Hz range. Small turbines can achieve higher blade tip velocities that can give low frequency noise of 20–20 kHz range.

To get a better feeling of the frequency ranges that are audible and are produced by wind turbines, we can see Table 1.

The levels of infrasound radiated by the large wind turbines are very low in comparison to other sources of acoustic energy in this frequency range. However, the annoyance is often connected with the periodic nature of the emitted sounds rather than the frequency of the acoustic energy. Because low frequencies travel farther than the high frequencies due to their long wavelengths, they become a cause of irritation for residents living not so close to wind farms.

Sound is a series of waves that travel through air in the form of disturbances and reaches our eardrums. Any natural or artificial obstacles such as hills and buildings play a shielding effect role, reflecting the sound, while most of the times absorbing some of the acoustic energy. Trees and ground vegetation also attenuate sound and change its directivity patterns. The distance and obstacles that are located between the source and the receiver have a significant impact on the acoustic ‘line of sight’.

The ways to reduce noise from wind turbines are mostly focused on blade design optimisation and choice of wind farm location as it still a new field and new techniques are under development. A major challenge that needs to be addressed before abatement techniques are put in action; is to establish accurate measurement methods of wind turbine noise in order to define the parameters of the problem and find an appropriate acoustic solution for it. Noise measurements from wind turbines is a complex task because the background noise levels are comparable to the noise levels from wind turbine when it starts operating at certain wind speeds. This is the reason a commonly used approach that overcomes the above issue needs to be established.

Current acoustic treatment methods range from designing quieter wind turbine compartments to placing wind turbines as far as possible from residential areas. Wind turbine blades are aerodynamically shaped to avoid causing abrupt airflow disturbances and the turbine is placed upwind to eliminate interference of the flow between the tower and the wind turbine blades. Apart from aerodynamic solutions other treatments include sound proofing of the nacelle to reduce mechanical noise and careful selection of the wind turbine site to attenuate noise until it reaches the receiver.

Table 1: Important frequency ranges.

<table>
<thead>
<tr>
<th>Description</th>
<th>Frequency range</th>
</tr>
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<tbody>
<tr>
<td>Normal hearing</td>
<td>20 Hz to 20 kHz</td>
</tr>
<tr>
<td>Normal speech</td>
<td>100 Hz to 3 kHz</td>
</tr>
<tr>
<td>Low frequency</td>
<td>20–200 Hz</td>
</tr>
<tr>
<td>Infra sound</td>
<td>&lt;16 Hz</td>
</tr>
</tbody>
</table>
It is common sense that the extensive use of wind turbines is included in the current and the future environmental plans of every country, fact which will certainly place a strong demand for dealing noise issues in the near future.

2 Noise types and patterns

2.1 Sources of wind turbine sound

The sources of sounds emitted from operating wind turbines can be divided into two categories: (1) mechanical sounds, from the interaction of turbine components, and (2) aerodynamic sounds, produced by the flow of air over the blades. A summary of each of these sound generation mechanisms follows, and a more detailed review is included in [1].

More specifically, wind turbines produce energy by the rotational motion of the blades due to the wind flow. Rotating blades are known to emit three different types of acoustic signature:

- tonal noise
- broadband noise
- mechanical noise

Tonal noise is characterised by discrete frequencies and it is generated by the periodic rotation of the turbine blades. An example of tonal noise history is shown in Fig. 1. Tonal noise is caused by the unsteady air velocity due to the blade rotation which disturbs the flow on the blade surface. It is directional as it is produced at the direction the blades meet the airflow and therefore is dependent on the observer position.

As the blades rotate the load on the blade surface changes periodically causing analogous changes in the unsteady pressure on the blade surface inducing sound waves. Depending on the position of the observer in relation to the turbine while
the blade is in operation the observer receives variable acoustic signals. Also the sound component in the direction of the observer varies with time and a sound wave is generated. Normally, the flow through the blades is distorted (non-uniform) and therefore the angle of attack of each blade varies continuously as the turbine rotates causing the sound generation to be highly directional and more frequent. This change in the angle of attack can be very abrupt especially when velocity discontinuities occur in the inflow profile resulting in rapid changes in the blade loading, flow disturbance and therefore generation of acoustic waves.

Such type of acoustic waves can be produced when the mounting tower of the wind turbine interferes with the flow passing through the wind turbine blades. This causes local velocity instabilities in the flow field which moves through the blades producing pulsing low frequency noise. A downwind design is shown in Fig. 2a.

It becomes self-explanatory that when the reverse order occurs, the disturbances ease as the blades encounter only the free field flow disturbances. An upwind turbine is shown in Fig. 2b.

The noise generated by downwind designs has low frequency in the range of 20–100 Hz and it is caused when the turbine blade encounters localised flow deficiencies due to the flow around a tower. It can also be impulsive described by short acoustic impulses or thumping sounds that vary in amplitude with time. It is caused by the interaction of wind turbine blades with disturbed air flow around the tower of a downwind machine.

2.2 Infrasound

A special category of the tonal noise released by wind turbines is infrasound. As we have already mentioned while low frequency ranges at the bottom of human perception (10–200 Hz), the infrasound is below the common limit of human perception. Sound with frequency below 20 Hz is generally considered infrasound, even though there may be some human perception in that range. A distinctive characteristic of infrasound is that it can travel very far because of its long wavelength that dissipates with a low rate and therefore it makes it easier to ‘survive’ and be present in our everyday life.

Figure 2: (a) Downwind turbine; (b) upwind turbine.
Considering the nature of infrasound, it becomes apparent that downwind wind turbines are more likely to produce significant levels of infrasound levels. This is because the tower–blade flow interaction creates air velocity instabilities that produce very low frequency acoustic waves called infrasound. Although downwind wind turbines have been used in the past, the modern technology has moved away from that noisy design to the upwind designs that give higher frequency noise levels and therefore are less irritating for humans.

One example of low frequency sound and infrasound from a modern turbine is shown in Fig. 3.

Broadband noise is dominated by high frequencies greater than 100 Hz and it is characterised by non-periodic signals that constitute an envelope that varies periodically. A typical broadband signal is shown in Fig. 4. Its main source of generation is the interaction of the wind turbine blades with atmospheric turbulence, and also described as a characteristic "swishing" or "whooshing" sound.

To determine the relative importance of tone noise and broadband noise we consider the narrow-band frequency spectrum of a signal. Figure 5 shows a typical spectrum of tonal and broadband noise. At higher frequencies the broadband random noise dominates the spectrum.

2.3 Mechanical generation of sound

A wind turbine consists of mechanical components that move or rotate in order to capture the motion of the turbine and convert it to energy. Sources of such sounds include:

1. Gearbox
2. Generator
3. Yaw drives
4. Cooling fans
5. Auxiliary equipment (e.g. hydraulics)
Generally the mechanical sound is low frequency sound although it might have a broadband component that comes from the relative motion from each of the above parts. The turbine's metal parts come in contact with each other, such as the generator, the gearbox and the shafts and they emit noise and as they vibrate.

Because wind turbines can have different constructions they might have different sound emissions because of the way in which they operate. For instance they may have blades which are rigidly attached to the hub or may have blades that can
be pitched (rotated around their long axis). Some have rotors that always turn at a constant or near-constant speed while other designs might change the rotor speed as the wind changes. Wind turbine rotors may be upwind or downwind of the tower.

It is worth mentioning that the hub, rotor, and tower may act as loudspeakers, transmitting the mechanical sound and radiating it. The transmission of noise from the mechanical parts of a wind turbine can take place in two ways:

- structure-borne
- air-borne

Structure-borne sound [3] is a sound that is propagated through structures as vibration and subsequently radiated as sound. The intensity and the frequency of structure-borne sound depend on many factors such as the rotational speed of the wind turbine, as well as the type and the material of the mechanical parts that vibrate. Air-borne [4] means that the sound is directly propagated from the component surface or interior into the air.

Structure-borne sound is transmitted along other structural components before it is radiated into the air. For example, Fig. 6 shows the type of transmission path and the sound power levels for the individual components for a 2 MW wind turbine. Note that the main source of mechanical sounds in this example is the gearbox, which radiates sounds from the nacelle surfaces and the machinery enclosure.

Utility scale turbines are usually insulated to prevent mechanical noise from proliferating outside the nacelle or tower. Small turbines are more likely to produce noticeable mechanical noise because of insufficient insulation.

![Figure 6: Sound power levels of wind turbine components [1].](image-url)
3 Sound level

In order to understand how sound propagate we need to identify the nature of sound. Sound is a series of waves and it is characterised by two properties: amplitude (loudness) and frequency. Therefore there are sounds that consist of combinations of low and high magnitude with low and high frequency. The human ear can detect a very wide range of both sound levels and frequencies, but it is more sensitive to some frequencies than others.

Sound is generated by numerous mechanisms and is always associated with rapid small-scale pressure fluctuations, which produce sensations in the human ear. Sound waves are characterised in terms of their amplitude, wavelength ($\lambda$), frequency ($f$) and speed ($c$), as follows:

$$c = \lambda f$$

The speed of sound is a function of the medium through which it travels, and it generally travels faster in more dense mediums. Sound propagates as a wave as shown in Fig. 7. In air it travels at a speed of 340 m/s and in water 1500 m/s. As sound travels it transports acoustic energy with it which attenuates the further it travels. As the sound propagates it disturbs the fluid from its mean state.

The pressure at a position $x$ is $p = p_0 + p'(x, t)$ with $p'/p_0 << 1$.

Sound is measured in dB and the sound pressure level (SPL) is defined as

$$SPL = 20 \log_{10}(p'_{\text{rms}} / 2 \times 10^{-5}) \text{dB}$$

where $p'_{\text{rms}}$ is the mean square level of fluctuation [5].

As sound energy travels through the air, it creates a sound wave that exerts pressure on receivers such as an ear drum or microphone and it makes our eardrums vibrate [6]. Human whisper releases an acoustic power of $10^{-10}$ W and a large jet transport at take off emits about 10 W.

The threshold of pain is between 130 and 140 dB. The threshold of hearing is around 0 dB. The sound power level from a single wind turbine is usually between 90 and 105 dB(A). Figure 8 shows a few examples of sound pressure levels from everyday life.

As described above, the decibel scale is logarithmic. A sound level measurement that combines all frequencies into a single weighted reading is defined as a
broadband sound level. For the determination of the human ear's response to changes in sound, sound level meters are generally equipped with filters that give less weight to the lower frequencies. There are a number of filters that accomplish this:

- **A-weighting**: This is the most common scale for assessing environmental and occupational noise. It approximates the response of the human ear to sounds of medium intensity.
- **B-weighting**: This weighting is not commonly used. It approximates the ear for medium-loud sounds, around 70 dB.
- **C-weighting**: Approximates response of human ear to loud sounds. It can be used for low frequency sound.
- **G-weighting**: Designed for infrasound.

Details of these scales are discussed by Beranek and Ver [7].

Once the A-weighted sound pressure is measured over a period of time, it is possible to determine a number of statistical descriptions of time-varying sound...
and to account for the greater community sensitivity to night-time sound levels [8]. Terms commonly used in describing environmental sound include:

- **L10, L50, and L90**: The A-weighted sound levels that are exceeded 10%, 50%, and 90% of the time, respectively.
- **Leq: Equivalent Sound Level**: The average A-weighted SPL which gives the same total energy as the varying sound level during the measurement period of time.
- **Ldn: Day-Night Level**: The average A-weighted sound level during a 24-h day, obtained after addition of 10 dB to levels measured in the night between 10 p.m. and 7 a.m.

### 4 Factors that affect wind turbine noise propagation

Propagation refers to how sound travels. Attenuation refers to how sound is reduced by various factors. Many factors contribute to how sound propagates and is attenuated, including air temperature, humidity, barriers, reflections, and ground surface.

The ability to hear a wind turbine also depends on the ambient sound level. When the background sounds and wind turbine sounds are of the same magnitude, the wind turbine sound gets lost in the background. The most important factors are:

- Source characteristics (directivity, height)
- Distance of the source from the observer
- Air absorption
- Ground effects (reflection and absorption on the ground)
- Weather effects (wind speed, temperature, humidity)
- Shape of the land – land topology

#### 4.1 Source characteristics

The source characteristics such as height and directivity can affect the sound propagation path and its power or intensity. The higher a source is located, the higher the sound power loss rate is. This means that wind turbine that is mounted on a tower relatively high to a residential estate it has relatively low noise impact on the residents as the sound energy attenuates until it reaches the human ear. The directivity of an acoustic source has also a significant impact on the sound perceived by the human ear. For example when the sound is forced to follow a certain directional path determined by the geometrical shape it is placed in, such as conical speaker, the radiation field is concentrated towards a certain area leaving quite zones in the opposite direction.

In general, as sound propagates without obstruction from a point source, the initial sound energy decreases and it is being distributed over a larger and larger area as the distance from the source increases.
For example, in the case of spherical excitation or a monopole noise source the sound is radiated in all directions and the sound level is reduced by 6 dB for each doubling of distance from the source.

A moving train is a line source, and it emits equal sound power output per unit length of the train line. A line source produces cylindrical spreading, resulting in a sound level reduction of 3 dB per doubling of distance. The spherical propagation is associated with the three-dimensional propagation and the line source with the one-dimensional sound wave propagation, respectively. When two monopole sources of equal strength but opposite phase are put together at a short distance they produce a dipole, which is referred as two-dimensional sound wave propagation. Figure 9 shows the sound directivities of a monopole and a dipole.

4.2 Air absorption

Air absorption of sound is driven by two mechanisms: molecular relaxation and air viscosity. Molecular relaxation is the transition of a molecule from an excited energy level to another excited level of lower energy. High frequencies are absorbed more than low because they have short wave length and therefore the waves dissipate as they travel through the air molecules. The air absorption must be taken into account at high frequencies when calculating the reverberation time of a room. It is due to friction between air particles as the sound wave travels through the air. The amount of absorption depends on the temperature and humidity of the atmosphere [10].

4.3 Ground absorption

The ground can contribute to the sound attenuation by two mechanisms sound absorption and sound reflection. When the sound hits the ground the acoustic energy loss depends on the reflection coefficient of the surface. On hard surfaces attenuation occurs due to the acoustic energy losses on reflection while on porous surfaces, sound levels are being reduced due to the increased absorption of the ground. High frequencies are generally attenuated more than low frequencies.

The reflection coefficient depends on the impedance of the two media, in this case, air and ground, and represents the absorbency of the ground in a homogeneous
way, i.e. the entire infinite plane is assigned with the same reflection coefficient [11].

When the source and receiver are both close to the ground, the sound wave reflected from the ground may interfere destructively with the direct wave. This effect (called the ground effect [12]) is normally noticed over distances of several meters and more, and in the frequency range of 200–600 Hz.

4.4 Land topology

The topology and the shape of the land can significantly affect the magnitude and the direction of sound. For example, trees and high altitude vegetation can contribute to the sound attenuation. However, a long series of trees several hundreds of meters long is required in order to achieve significant attenuation.

Also significant attenuation can be achieved by the use of natural or artificial barriers or obstacles such as hills and buildings that exist on the ground. The level of impact on the sound reduction of an obstacle depends on whether it is high enough to obscure the ‘line of sight’ between the noise source and receiver.

Due to their short wavelength, high frequencies are trapped by the obstacles preventing them from travelling far, unlike the low frequencies.

Similarly to the ground reflection theory, the material of the barriers plays a dominant role in the sound propagation and this is the reason barriers are often used for noise treatment purposes [13]. A barrier is most effective when placed either very close to the source or to the receiver.

4.5 Weather effects, wind and temperature gradients

The wind and the temperature can affect the propagation of the sound in the atmosphere under certain weather conditions. The mean uniform wind flow determines the background noise levels and it alters the sound pressure downwind and upwind. When a wind is blowing there will always be a wind gradient. A wind gradient results in sound waves propagating upwind being ‘bent’ upwards and those propagating downwind being ‘bent’ downwards.

The temperature is another factor that affects sound radiation however; it becomes important only when the high temperature gradients occur. Such dramatic changes in the temperature profile are unlikely to happen in the atmosphere close to the ground but they can occur at high altitude layers. Any temperature differences in the atmosphere can cause local variations in the sound speed since the latter depends on the temperature of the gas. Higher temperatures produce higher speeds of sound. When sound waves are propagating through the atmosphere and meet a region of non-uniformity, some of their energy is re-directed into many other directions. This phenomenon is called refraction [14].

5 Measurement techniques and challenges

As we have already mentioned in previous sections, low frequency noise emissions from wind turbines have given rise to health effects to neighbours. Resident
complaints about the irritating noise from the wind turbines has led scientists and engineers to invent ways to assess the levels of noise in the near and in the far field and eventually close to dwellings where residents live.

Measuring noise from wind turbines is not an easy task due to the fact that background noise levels increase as the wind speed increases. So, as the wind turbines start rotating the background noise levels are being intensified. Also when we think that the wind turbines are placed outdoors where trees, leaves and vegetation in general, are present then it becomes apparent that the background noise is comparable to the noise emissions from the turbines. This makes it extremely difficult to measure sound from wind turbines accurately. At wind speeds around 8 m/s and above, it generally becomes a quite abstruse issue to discuss sound emissions from modern wind turbines, since background noise will generally mask any turbine noise completely.

To assess the potential levels of infrasound and low frequency noise around a wind farm and at neighbouring locations of interest, the measurements are undertaken using a measuring system capable of capturing frequencies from 1 Hz to 20 kHz. Measurements are performed at internal and external locations placing the microphones at locations where noise is considered more audible when occurred. Assuming that the appropriate equipment is being used and the calibration procedures have been followed, the standard procedure to take noise measurements is the following:

- Ambient background noise levels evaluation.
- Spot measurements of noise levels inside dwellings subject to access or prediction if access is prohibited.
- Exterior acoustic measurements at neighbouring facades to assess annoyance.
- Spot measurements of wind speed.
- The evaluation and reporting of measurements made.

It is worth mentioning that there is a variety of sophisticated model available but they are all at developing stages. A typical time history of measured sound pressure levels is shown in Fig. 10.

5.1 For small wind turbines.

Our experience indicates that in practice, field measuring is a challenging task not only due to the difficulty to estimate background levels but also due to the complexity of the required experimental set up. One has to count for the directional noise emission depending on which side the wind is blowing and the fact that modern small wind turbines rotate around their vertical axis making the noise measurement techniques even more demanding.

Because of the importance of background noise in determining the acceptability of the overall noise level, it is crucial to measure the background ambient noise levels for all the wind conditions in which the wind turbine will be operating. Sound propagation is a function of the source sound characteristics (direction and
height), distance, air absorption, reflection and absorption and weather effects such as changes of wind speed and temperature with height.

Given the current situation difficulties, a good idea to tackle with such a problem would be at a first stage to use the anechoic chamber to remove background noise and depending on the results, to employ measurement techniques and methods which enable characterisation of the noise emission from wind turbines at a receptor location. The use of a vertical board mounted with a microphone suggested in the document of IEA [16] recommended practices in case of such a problem. The document recommends the use of a large vertical board with a microphone at the designated position with its diaphragm flushed with the board surface or to suppress wind induced noise on a microphone. Figure 11 shows the background noise levels and the noise levels from a wind turbine in operation.

6 Abatement methods

In principle there are two ways to reduce noise: either make the source less noisy or make the receiver more sound proof. The same principle can be applied to the wind turbines when considered as noise sources.

Also if we think the factors that affect the noise propagation we can easily guess a few measures we can take in order to control noise from wind turbines. More specifically locating wind farms as far and as high as possible from residential areas and improving the sound insulation in houses we can significantly limit the sound levels received by the human ears. Natural obstacles and vegetation can also prevent noise from reaching people’s homes.

A systematic and scientific consideration of all those factors along with real time measurements leads to a study known as environmental impact assessment. Such assessment is essential to evaluate the current environmental conditions at a
proposed erection of a wind farm. Among others, it assesses how the proposed wind farm will effect the environment and the public health, and whether any resultant changes in conditions are deemed acceptable or unacceptable. Best code guidelines and policy standards are being practised and followed in order to ensure environmental protection including noise and nuisance.

Recalling that the type of noise generated from a wind turbine can be mechanical and aerodynamic, we are able to investigate and find solutions for noise treatment.

Starting with the mechanical parts of a wind turbine that rotate or move in relation to each other such as gears that are creating structure-borne noise and vibration, it becomes clear about the need for designing gearboxes for quiet operation. Wind turbines use special gearboxes, in which the gear wheels are designed slightly flexible in order to reduce mechanical noise. One way of doing this is to ensure that the steel wheels of the gearbox have a semi-soft, flexible core, but a hard surface to ensure strength and long time wear.

In addition to designing quiet parts, insulating those parts seems to be another way to tackle that type of noise. Soundproofing and mounting equipment on sound dampening buffer pads helps to deal with this issue. In addition, special sound dampening buffer pads separate the gearboxes from the nacelle frame to minimise transmission of vibrations to the tower.

There are limited acoustic solutions that can be applied to reduce noise from the mechanical movements due to the space restriction inside the nacelle as well as the necessity not to disturb the efficient functionality of the mechanical parts with added acoustic treatment. Although for large wind turbines mechanical noise is not...
much of an issue since those are located far from dwellings, for the small house, mounted wind turbines vibration can have significant impact on people’s lives living in the house where the wind turbine is attached.

Moving on to the aerodynamic noise, there are various techniques or even technologies to decrease sound from the wind turbine blades. As somebody would expect most of those techniques originate from designing more aerodynamic blades [18] and adjusting the rotational speed of the turbine.

Again, revising section ‘sources of wind turbine sound’ we can remind ourselves what causes aerodynamic noise and therefore suggest potential solutions. Some of the noise causes we have discussed concern downwind designs, blade speed and shape and interaction of the airflow between the tower and the wind turbine.

Nowadays most rotors are upwind i.e. the rotor faces into the wind, reducing the risk of causing localised flow instabilities that are responsible for impulsive noise. Although there are still quite a few downwind turbines (where the rotor faces away from the wind) in use, new improved design features have been incorporated aiming at reducing impulsive noise such as increasing the distance between rotor and tower.

In addition to designing upwind turbines the shape of the tower and the nacelle are aerodynamically streamlined in order to reduce any noise that is created by the wind passing the turbine.

To limit the generation of aerodynamic sounds from wind turbines the rotor’s rotational speed may be restricted in order to reduce the tip speeds. Large variable speed wind turbines often rotate at slower speeds in low winds, and in increased speeds in higher winds until the limiting rotor speed is reached. This results in much quieter operation in low winds than a comparable constant speed wind turbine. Many modern wind turbines have embedded special control programs that reduce the inflow angle and rpm of the rotor depending on the time of day or year, the wind speed and the wind direction. The noise can be significantly reduced at the expense of power output.

Wind turbine blades are constantly being redesigned to make them more efficient and less noisy. The broadband tip vortex noise caused by rotating wind turbines can be tackled by giving to the blade tip an aerodynamic shape that decreases generation of vorticity [19]. Forward sweeping into the direction of the incoming flow of the blade could result in quieter operation. Figure 12 shows graphically how design changes in the blade tip and shape can result in noise reduction i.e. how three different blade tip geometries can produce three different noise profiles [20].

When it comes to small wind turbines (under 30 kW) the ways to reduce noise are similar to those for large turbines. This means that they also have often variable-speed controls. The interesting fact is that small wind turbine designs may even have higher tip speeds in high winds than large wind turbines. This can result in greater sound generation than would be expected, compared to larger machines. Many modern microwind turbines rotate over their vertical axis regulating power in high winds by turning out of the wind. This additional functionality in operation
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can affect the nature of the sound generation from the wind turbine during power regulation. In general domestic wind turbines apart from noise effects can generate vibration signals which are transmitted through the walls causing annoyance to people inside the house. Ways to deal with those problems are associated with increased wall insulation and with locating the turbine at a distance from the residential areas at a height over 3 m from the ground and often being kept switched off during the night.

7 Noise standards

Currently, there are no common international noise standards or regulations for sound pressure levels from wind turbines. Every country, however, defines noise limits and regulations for human exposure depending on the time of the day.

A standard that is being internationally used is:


The IEC 61400-11 standard defines:

- The quality, type and calibration of instrumentation to be used for sound and wind speed measurements.
- Locations and types of measurements to be made.
- Data reduction and reporting requirements.

The standard requires measurements of broad band sound, sound levels in one-third octave bands and in narrow-bands. These measurements are all used to determine the sound power level of the wind turbine.

8 Present and future

Noise from wind turbines is an issue that is gaining increasing concern for government bodies, regulators and the public. The pressure on governments to cut carbon
emissions, forces them to make extensive use in their future environmental plans to install as many wind turbine as necessary. It becomes apparent that a number of improvements in standards and regulations is needed to ensure that communities can reliably anticipate noise from wind turbines and to ensure that the data are available to make those sound estimations.

Also research and development in establishing commonly used standards is essential for manufactures and planners to be able to conduct accurate measurements.

We have already mentioned in this chapter that the challenge in measuring noise from wind turbines is that the background noise levels increase as the wind speed increases making it difficult to accurately measure sound levels from the turbines. It is therefore essential that more investigation is being carried out into measuring background noise as a function of both time of day and wind speed and also taking into consideration the factors that affect propagation such as reflection and absorption, ground topology and weather phenomena. This further research would help in establishing accurate and practical noise standards that consequently would inform and guide manufacturers and installers to make comprehensive sound power level measurements, based on new standards, available to the public.

Standards are also needed for the measurement of noise from small wind turbines. These should encounter not only for noise but also for vibration effects since this seems to be a major problem for house mounted wind turbines. These would also inform planners and installers on their decision to select type of wind turbine, location as well as hours of operation.

References


