Contemporary Problems in Appropriate Technology

Assessing the Noise Emitted by Small Wind Turbines

By

Adam Sacora

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Introduction

The idea of using wind energy to turn electric generators to produce electricity is not a new idea. Wind energy can supply clean, renewable energy without any pollutants or environmental impact. There is no destruction of natural habitat, pollution of water, soil, or air involved with the production of wind energy. This source of clean, renewable energy can lift the yoke of fossil fuels from around our neck. What is new and amazing about wind energy is how efficient the latest generations of wind turbine generators are at converting wind energy into electricity.

There are a multitude of types, styles, manufactures, sizes and scales at which wind turbines convert wind energy to electricity. There are large scale wind farms where any one of hundreds of giant wind turbine generates up to two mega watts at a time. This research project will focus on a smaller scale of wind turbines, the scale that residential home owners would put up in the back field, or the independent homesteader would use to power his/her off the grid home. Ranging in size from 30watts to 10kilowatts, these turbines can supplement a single home with power or support several off-grid homes. These small machines are appropriate for the production of electricity on good wind sites, and as close to the electrical needs as possible to avoid power loss do to voltage drop over long distance.

Because small wind turbines need to be fairly close to the house(s) it supplies electricity to, the issue of noise emitted by the turbine while operating in high winds poses several questions. How does this noise affect the home owner? Does this noise bother the neighbors? Will it keep a person up all night? Will it affect decisions regarding political geographic zoning? Is this noise a source of friction in this technology transfer? Would this believed noise have neighbors up in arms about a local wind turbine being installed? Can a turbine be put right next to the house, or does it have to be a long distance away? If so, how far away is sufficient? Are some turbines noisier than others? What characteristics effect the noise made by a small wind turbine?

There is one certainty with this appropriate technology; small scale wind energy is a good thing. It can supply energy to single or multiple homes. It can be used in off grid applications or where running electrical lines is not an option. Using an energy source that is right above ones own property means security and independence from reliance on foreign resources. It is an economical choice to produce electricity with wind power; it is now very competitive with the price of producing electricity with even the cheapest methods such as coal, hydro, natural gas or even nuclear. By producing one's own electricity through wind energy one can offset the production of other more destructive production methods of electricity. This offset of energy production keeps the environment from being degraded and polluted more with emissions such as carbon monoxide, sulfur oxide, nitrogen oxide, volatile organics and other green house gasses. And unlike other resources, wind is abundant and renewable; we aren't going to run out of it, ever. This clean, environmentally friendly, secure, independent, economical, and renewable energy is in the sky waiting for each one of us to reach up and convert into usable electricity for residential and small business application the globe over.

There are only a few reasons why small scale wind energy is not in abundant use today. The focus of this research will be on the problem of noise emissions from small wind turbines.

Problem Statement

There is a dependent relationship between wind speed and noise emitted by small wind turbines. The faster the wind is blowing, the faster the wind turbine rotor turns and the more energy the wind turbine generates. The problem is that the faster the turbine turns in high winds, the louder the noise emissions. This noise comes from aerodynamics and mechanical chattering. These noise emissions are loud enough to be recognized by the human ear within a certain decibel level and sound pressure range. The range or distance at which this noise is heard is also a dependent factor. Each wind turbine produces noise to its own character and level, all depending on many variables taken into account.

The goal for this research project is to determine what levels of noise are emitted at variable wind speeds and how far away this noise emitted by small wind turbines is recognized by the human ear. Research is needed to find out correct procedures in measuring, collecting data, analyzing and reporting results of tests and studies. Background research on noise emissions tests done by other organizations and groups is critical to comparing results and analyzing data. It is critical in analyzing results to isolate any variables and stay true to scientific procedures.

For this research project of noise emitted by small wind turbines I will conduct my own experiments with one or more of the small wind turbines located on the Beech Mountain Small Wind Demonstration Site, North Carolina.

Sound equipment, tools, data loggers, analyzing software and materials will be supplied by the Western North Carolina Small Wind Initiative state grant in joint with the Technology Department at Appalachian State University.

Chapter 2

Literature Review

It is critical to learn about the topics of wind turbine generated noise, sound characteristics, measurement techniques, as well as reviewing tests and studies done in the past in order to fully grasp the concepts, theories, language, equations and methods to properly research the field of noise pollution by wind turbines. Starting broad, then narrowing it down to specifics, I have researched and read up on noise caused by small wind turbines and will now compile an orderly write up of what my research has entailed and what it has brought to light.

What is Noise?

"Noise is a very subjective topic with people. Sounds that are soothing to one person may make another crazy" (Sargillo, 1997)

Noise from wind turbines can be defined as "unwanted sound" (RERL, 2002). Noise emitted from wind turbines is an issue that must be decided upon in an objective way. As large wind turbines are being located closer to the power load centers that are heavily populated, and smaller scale wind turbines are being used in residential areas, developing quiet wind turbines become increasingly important (Wind and Power: Today and Tomorrow p.29, 2004).

Unwanted noise can be categorized depending on "1) the level of intensity, frequency, frequency distribution and patterns of the noise source; 2) background noise levels; 3) the terrain between emitter and receptor; and 4) the nature of the noise receptor" (RERL, 2002).

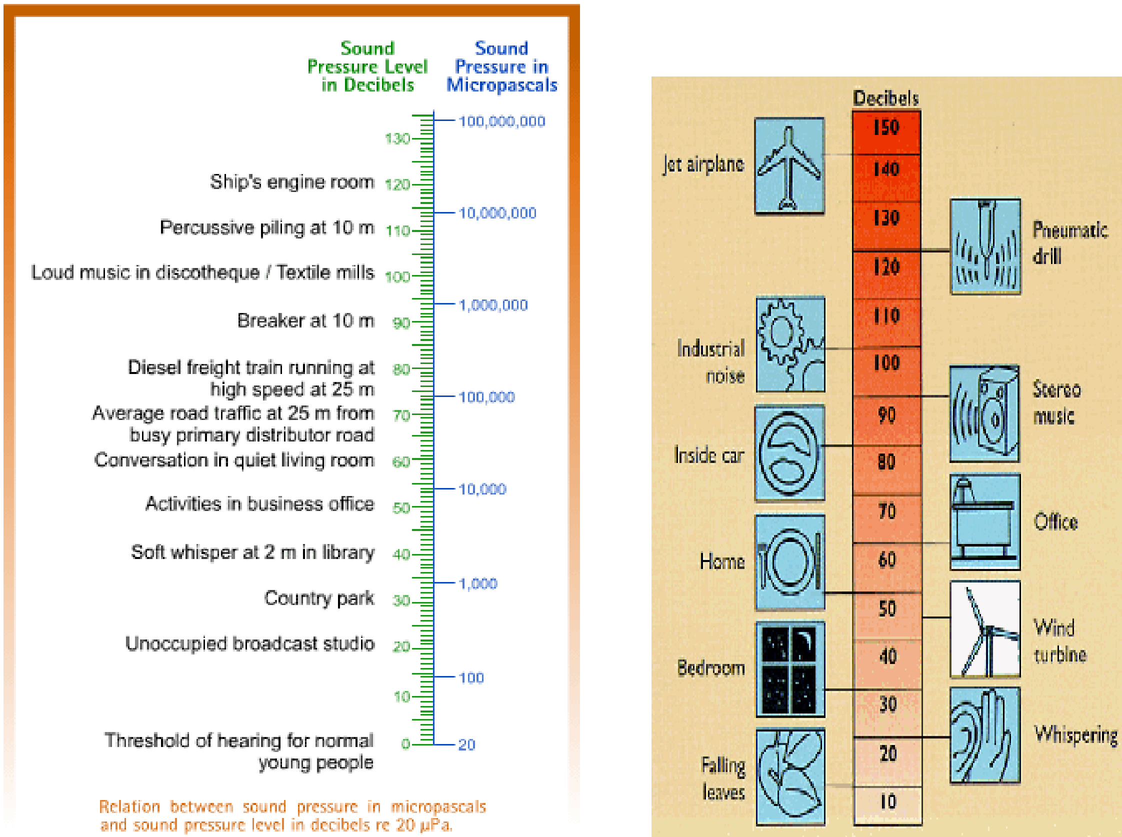
These effects can vary with each individual, but three general categories of effects on individuals can be distinguished. The National Wind Coordinating Committee in 1998 defined these effects from noise on individuals as:

> 1) Subjective effects including annoyance, nuisance, dissatisfaction.
>
> 2) Interference with activities such as speech, sleep and learning.
>
> 3) Physiological effects such as anxiety, tinnitus, or hearing loss.
>
> In almost all cases, the sound level associated with wind turbines produce effects only in the first two categories (NWCC, 1998).

Noise and Sound Measurement Scales

Research has found that sound pressure is a property of sound at a given observer location and can be measured by a microphone, expressed in decibels, dB. (RERL, 2002)

“Sound detectible by the human ear is measured in decibels, or dB, with a device known as a decibel meter” (Sagrillo, 1997). In his publishing *small wind generators and noise*, author Mick Sagrillo reports that the human ear distinguishes sound differences of about 3 dB. This means that there must be a difference of 3 decibels before the human ear can distinguish a sound from other background noise. To get a general feel for what a measured noise is relative to decibel levels, figure 1 compares typical noise emissions.



<u>Figure 1 Example of Decibel Levels and Typical Noise Pollution</u>

When observing sound from different distances, it is important to understand the intensity of sound and how it is affected by distance from the source of noise. The Intensity of sound, as described by the *Glenbrook Classroom Physics* online, is usually expressed in Watts per Meter^2 or as represented in the equation in figure 2.

$$\text{Intensity} = \frac{\text{Energy}}{\text{Time} * \text{Area}} \quad \text{or} \quad \text{Intensity} = \frac{\text{Power}}{\text{Area}}$$

<u>Figure 2 The Sound Intensity Equation</u>

As a sound wave carries its energy through a two-dimensional or three-dimensional space, the intensity of the sound wave decreases with increasing distance from the source. The

> mathematical relationship between intensity and distance is sometimes referred to as an **inverse square relationship**. As the intensity varies inversely with the square of the distance from the source. So if the distance from the source is doubled (increased by a factor of 2), then the intensity is quartered (decreased by a factor of 4). Similarly, if the distance from the source is quadrupled, then the intensity is decreased by a factor of 16. (Physics classroom, 2004)

Figure 3 represents how sound travels through space as a function of distance from the source of sound. This image is provided from *Glenbrook Classroom Physics* website (2004).

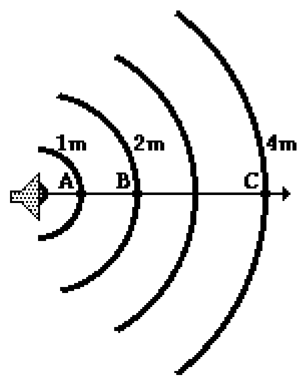


Figure 3 Sound Travels in Waves

The distance of the receptor from the source of sound is an important factor to consider when determining site selection or setbacks for wind turbines. Jim Green of the NREL is quoted at a small wind workshop (Boone, 2004) saying “noise dissipates as distance squared”. This is the inverse squared relationship as mentioned above

The Danish Wind Industry Association has published many facts on noise emitted by wind turbines. The graphs provided in figure 4 and figure 5 are off their web site and show how the numerical relationship between sound level and distance from the noise source.

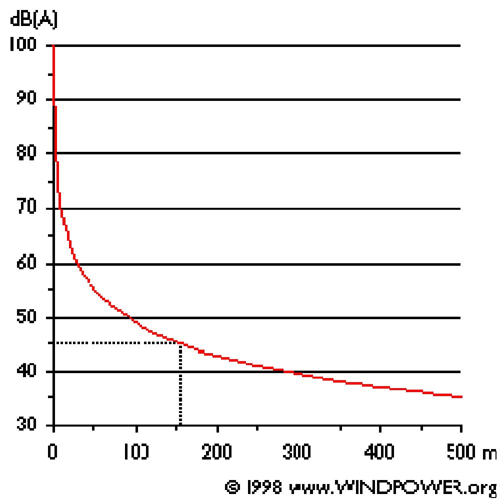


Figure 4 Decibel Level versus Distance

Sound Level by Distance from Source

Distance m	Sound Level Change dB(A)	Distance m	Sound Level Change dB(A)	Distance m	Sound Level Change dB(A)
9	-30	100	-52	317	-62
16	-35	112	-53	355	-63
28	-40	126	-54	398	-64
40	-43	141	-55	447	-65
50	-45	159	-56	502	-66
56	-46	178	-57	563	-67
63	-47	200	-58	632	-68
71	-49	224	-59	709	-69
80	-50	251	-60	795	-70
89	-51	282	-61	892	-71

Figure 5 Sound Variance with Distance

Sources of Wind Turbine Noise

There are several sources of the noise emitted by wind turbines, and some that are not emitted by the wind turbine but need addressing as they can affect the level of discerned sound by a wind turbine. There is noise from aerodynamics, mechanical noise, noise from certain turbine operations and even background noise must be considered when discussing the noise emitted from small scale electricity generating wind turbine.

Background Noise

The noise a wind turbine emits that is intercepted by the human ear is dependent (among other variables) on the level of background noise, also known as ambient noise. "When the background noise and wind turbine noise are at the same magnitude, the wind turbine noise gets lost in the background" (RERL, 2002). Background noise can consist of traffic, dogs barking, children playing, lawnmowers, air conditioners, heaters, birds, animals, and insects and so on. Even wind is a background noise. The interaction of wind with trees, shrubs, landscape, buildings, power lines… are considered background noise, and this wind created background noise will vary with time of day, wind speed and direction in relation to receptor's location in relation to the source (RERL, 2002).

Aerodynamic Noise

Several complex air flow phenomena occur as wind passes by a wind turbine. Researchers have found that aerodynamic noise originates from the air flow around the blades. The RERL white paper of 2002 reports that there are three categories of aerodynamic noise: low frequency; inflow turbulence noise; and airfoil self noise.

1) Low frequency: generated when the rotating blade encounters localized flow deficiencies do to the air flow around a tower, wind speed changes, or wakes shed from other blades.

2) Inflow turbulence noise: generated by atmospheric turbulence. This atmospheric turbulence results in local force or pressure differences around the blade.

3) Airfoil self noise: generated by the air flow right along the surface of the airfoil. This may vary with tip composition or flow over slits and holes.

Residential sized wind turbines generate aerodynamic noise because they generate electricity at high rotor speeds which are due to the high rotational speed of the blades (Sagrillo, 1997).

Mechanical Noise

Mechanical noise originates from the relative motion of mechanical and electrical equipment. The mechanical noise is transmitted along the surface of the structure of the turbine and is radiated from its surface (RERL, 2002). On modern residential scale wind turbines there are only two to four moving parts, so the mechanical noise from these small turbines is minimal (Jim Green, 2004). These motions are typically 1) the rotation of the generator, 2) yaw motion 3) and a furling motion in a typical modern residential sized wind turbine.

Because residential sized wind turbines incorporate a direct drive train and have no gearbox or transmission as most utility scale wind turbines, most of the noise emitted by these small scale wind turbines is from the high rotational speed that induces aerodynamic noise (Sagrillo, 1997).

Wind Turbine Operation Noise

Unlike utility scale wind turbines that have physical braking mechanisms to control blade speed in high winds, the residential size wind turbines rely on mechanical ways to force them out of the path of high winds. Self braking mechanisms such as side furling, upward furling, angle governor and blade feathering governor are used individually or in combination to slow down high speed blade rotation in high winds (Jim Green, 2004). When such over-speed protection occurs, there is a significant amount of aerodynamic noise emitted, which is the noisiest time in the operation life of a small wind turbine. It can sound like a helicopter or a small plane taking off, but this only lasts for short bursts of time until the wind gust dies down.

Noise Propagation

Generally speaking, as noise propagates without hindrance from a source, the sound pressure level decreases. The initial energy in the noise is distributed over a larger and larger area as the distance from the source increases. “With spherical propagation, the sound pressure level is reduced by six dB per doubling of distance” (RERL, 2002). Other points of consideration reveled by the RERL 2002 white paper includes:

- Source characteristics such as directivity, height…
- Distance from the source to the observer
- Air absorption, which depends on frequency
- Ground effects such as reflectivity and absorption of sound on the ground, dependent on source height, terrain cover, ground properties, frequency…
- Blocking of sound by obstructions and uneven terrain such as trees, vegetation, hills, rocks, boulders…

- Weather effects such as wind direction, wind speed, change of wind speed, temperature change with height… prevailing wind direction can cause considerable differences in sound pressure levels between upwind and down wind positions.

Why have Test Procedures and Standards?

There are so many variables to isolate when testing acoustic noise emitted by any single wind turbine that a standard testing procedure must be used to save confusion. Because manufactures, scientists, and researchers a like need to measure noise emissions from wind turbines, a set of standard units, test equipment, test procedures and types of data collected must all follow a standard in order to be uniform. This is important so that manufactures can label their products in a uniform way so that buyers and installers can understand and compare product specifications. It is also important so researchers and developers can compare data reports on different turbines, therefore developing better, more efficient and quieter wind turbines.

What Standards so Use?

The standard for Acoustic Emission Measurement Techniques was set by the IEC (International Electrotechnical Commission) in 1984 and has been updated three times and last revised in 1994. The standard for Acoustic Emission Measurement Techniques is IEC 61400-11*.

Procedures

I shall following the IEC standard Acoustic Emission Measurement Techniques (IEC 61400-11*) as closely as possible.

The American Wind Energy Association has their own version of the IEC 61400-11* that is recognized by ANSI called the *Procedure for Measurement of Acoustic Emissions from Wind Turbine Generator System.* "This document presents measurement and reporting procedures for sound pressure levels from wind turbine generator systems (WTGS). It is intended to facilitate WTGS noise characterization specifications and development of noise propagation calculations." Soft cover, 35 pages, 1989 (AWEA, 2004).

For a small research project that is short on funds, it is almost impossible to follow the IEC 61400-11 standards to the letter. For lack of funding for such expensive equipment as called for by the IEC standards, I will follow as close as possible. Any deviation from the IEC 61400-11 standard will be documented as necessary.

Test Equipment

This is a refined list of measurement equipment used by the NREL in the Wind Generator System Acoustic Noise Test Report for the Bergey Excel Wind Turbine, which is in accordance with the IEC 61400-11* standard.

- Microphone
- Data logger
- Signal analyzer
- Preamplifier
- Calibrator
- Digital recorder
- Anemometer
- Wind vane

- Temperature sensor

Variables Tested

The NREL acoustic test (2002) collected two types of noise measurements: turbine and background. These two collections of data were then adjusted for corrections, and plotted against wind speed versus sound pressure level (dB). Figure 6 is an example of three South West Wind Power wind turbines and the acoustic test results in a plot.

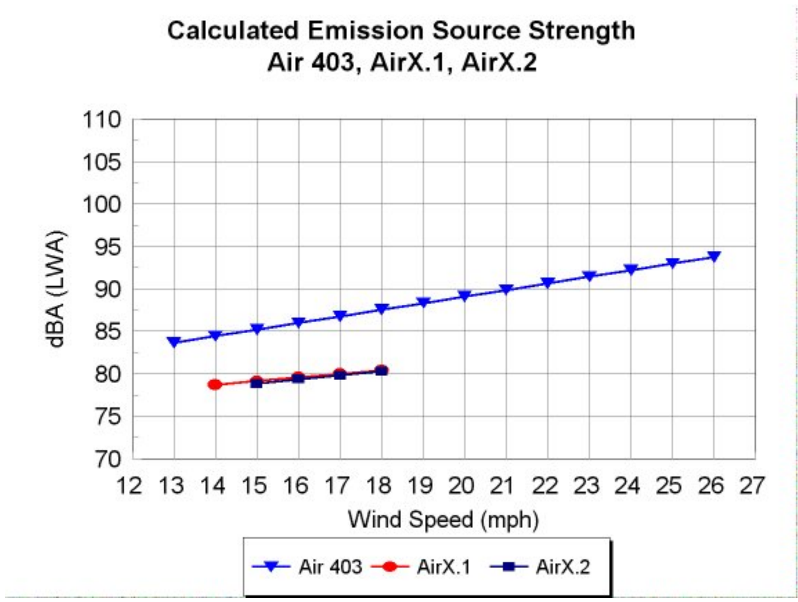


Figure 6 Example of Noise Emissions Plot

Other variables need to be isolated as best as possible. These variables include, but not excluding others, uncommon background noise such as heavy equipment, vehicles, other wind turbines in the background, thunder, wind in the microphone, etc…

Improvements in Noise Reduction Technology

The Wind Energy Facts Sheet by the AWEA (2004) gives a comprehensive list of what manufacturers have done to reduce wind turbine noise.

1) Most rotors are upwind: to avoid the impulsive noise caused when the blade passes behind the wind shadow of the tower as the rotor revolves in a downwind design.

2) Towers and nacelles have been streamlined: rounding or giving aerodynamic shape to any protruding features to reduce any noise created by the wind passing the turbine.

3) Soundproofing in nacelles has been increased: to insulate the sound produced by the generator, gears and other moving parts. Using soundproofing and mounting equipment on sound-dampening buffer pads to help deal with this issue.

4) Wind turbine blades have become more efficient: the wind energy industry and wind engineers have become more experienced, the design of turbines and blades are constantly being redesigned to be more efficient. The more efficient the blades are, the more wind energy is converted into rotational energy and the less aerodynamic noise is created.

How to Further Reduce Wind Turbine Noise

It is important to do a thorough site assessment before selecting a wind turbine. Noise analysis can be done based on operating characteristics of a specific wind turbine jointed with a particular wind site, type of terrain, and the distance between the possible wind site and the nearest residents. Selection of the appropriate wind turbine for the wind resources at a given site can reduce unwanted noise emissions.

Preconstruction noise surveys can be useful to find out typical background noises that might drown out any noise from the wind turbine.

The most common method is to simply require a setback or minimal distance from the wind turbine and the nearest neighbor or residence. (AWEA, 2004)

Chapter 3

Methodology

Procedures and Standards

There are strict procedures to follow when testing for wind turbine generated noise. The procedures that I am going to follow as close as possible will be the IEC 61400 part 11 which is the “Wind turbine generator systems – Part 11: Acoustic noise measurement techniques”. This is the official international standard for testing these types of noise emissions. I have acquired a copy of these standards through Jim Green at NREL wind energy testing facilities in Golden, Colorado. These standards are attached in the appendix.

Tools and Materials for Testing

Several tools and instruments will be used to measure, collect data, and analyze the outcome of these tests. Here is a list of tools and instruments that will be used for this research:

1. Sound Level Meter: This is a Type II SLM which has general grade precision. The IEC 61400-11 standard calls for a Type I SLM which is a precision grade instrument. This SLM was purchased from Testing Equipment Depot for $599.00 in October 2004. Below are the specs as shown on Testing Equipment Depot for the measurement instrument that will be used to measure and record the sound data:

   Extech 407764 Datalogging Sound Meter
   Meets ANSI S1.4 Type II and IEC 651 standards
   Autoranging over 6 ranges from 30 to 130dB with high accuracy to ±1.5dB and 0.1dB resolution

Large LCD display with function indication and fast 50 segment bar graph display
Time and Date are logged with data
Stored data can be easily transferred to a PC via RS-232 interface and analyzed using software & cable provided
A & C weighting and Fast/Slow response
Tripod mount provided on rear
Max Hold function
Internal self test when powered ON
Detachable 0.52" (13.2mm) diameter condenser microphone
Analog AC/DC recorder output 10m VDC/decibel
Optional microphone extension cable for measurements in enclosures and other remote locations (407764-EXT)
Dimensions: 10.4x2.8x0.8" (265x72x21mm)
Weight: 10oz
Complete with microphone wind cover, PC software on 3.5" diskette, Serial cable, 4 AA batteries and carrying case

2. Anemometer: This instrument measures the wind speed and has its own data logger with it. This equipment is provided by the Western North Carolina Small Wind Initiative (WNCSWI). There are two anemometers on each small wind turbine tower as specified heights. With these wind speeds at a known height, a small calculation will give the actual wind speed at hub height.
3. Wind Vane: This measures the wind direction and uses the same data logger as the anemometer. This is also provided by the WNCSWI.
4. Wind Screen: this is needed to block out the background noise of the wind when taking measurements in high winds. A primary wind screen came with the SLM that fits directly over the microphone. If this primary windscreen does not work in high winds, I will construct a secondary windscreen that is in a half spherical shape using wire mesh and closed-cell sound foam of 1” thickness.

5. Digital Recorder: I have yet to work this part out. A class mate of mine has experience and equipment to do this. I will fill this part of the paper in when I have the information.
6. Data Loggers: Two loggers are needed; the Logger for the Anemometer and Wind Vane is one and the same that collects wind data; and the sound level meter is a data logging model for all sound data collected.
7. Sound Board: ¾" plywood cut in a 1 meter diameter circle. This circular sound board is to be placed on the ground in a level, horizontal fashion. I will use sand under the sound board to level it as well as fill in all voids under the board to achieve a consistent sound measurement.
8. Sound Data Analyzing Software: This must interface with the SLM so that the data collected by the SLM can be analyzed and plotted by a PC. The Extech 407764 SLM came with and interfacing software to be used with that particular Data Logging Model.

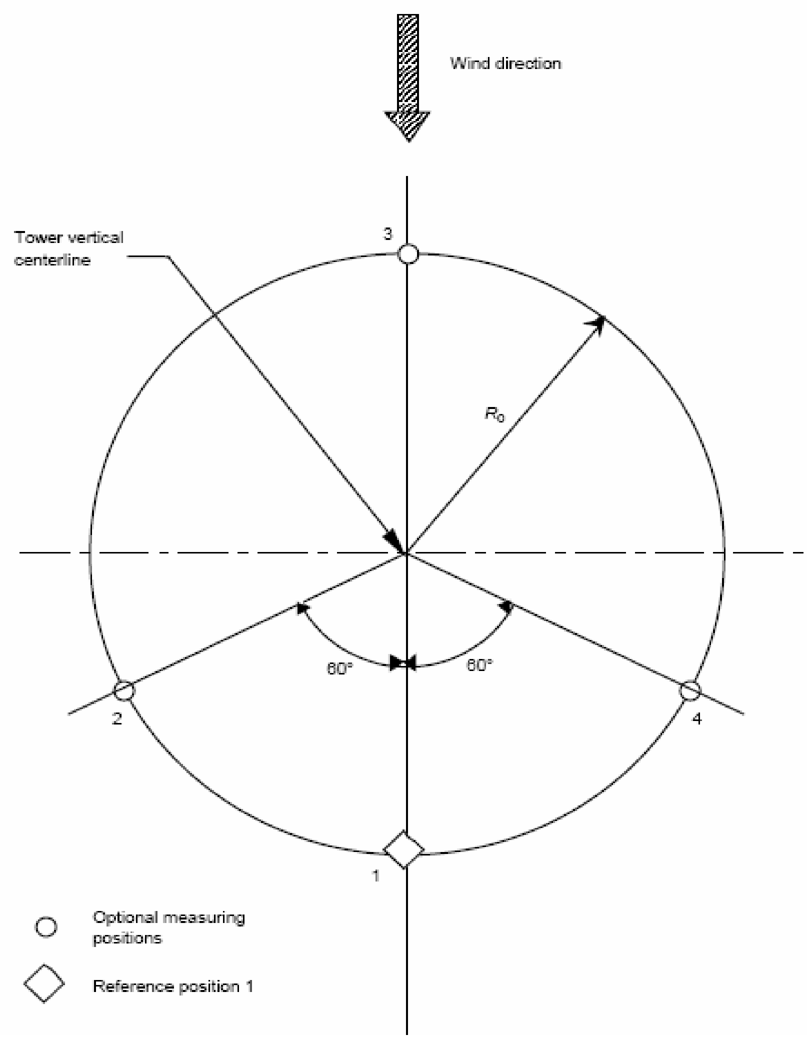
Testing Procedures

The procedures that will be used will follow the IEC 61400-11 standards as close as possible. Restrictions are financial. Deviations from the standard will be the SLM and frequency calculations associated with the SLM. The standards call for a Type I SLM which has a starting price of over $3000; we will be using an Extech 407764 Type II SLM. This set of tests will also focus on the relationship of noise level to distance and wind speed variables, instead of just wind speed versus noise level.

Variables to be measured:

1. **Sound Pressure Level** (measured in dB)**:** Two measurements will be taken: Ambient background noise: and turbine generated noise while under loaded operation. These measurements are one minute averages. The IEC 61400-11 standard set of calculations for determining and reporting sound pressure level will be used. See appendix.
2. **Wind Speed:** Using the two anemometers at specified heights on each wind turbine tower, I will be able to compute the wind speed at hub height. The equation that I will use to correct for hub height wind speed is the same equation used by Paul Gipe in his book Wind Energy Basics: $V/V_o=(H/H_o)^e$ were Vo is the wind speed at the original height, V is the wind speed at new height, Ho is the original height, and H is the new height. The exponent (^{e}) is the roughness exponent that corrects for turbulence from surrounding landscape. The Anemometer Data Loggers have a time signature and will be synchronized with the SLM which also has a time stamp on the data it collects so that both sound and wind data will be collected in simultaneous harmony. The data logger on these anemometers is set to log one minute average wind speeds as well.
3. **Wind Direction:** Wind vanes are placed on all the wind turbine towers as well as anemometers. The data loggers for the anemometers also log the wind direction simultaneously as it collects wind speed. This data on wind direction also has a time stamp so the wind direction data will be synchronized with the SLM data and the wind speed data.

4. **Reference Positions:** The IEC standards have specified exact locations in relation to the wind direction to locate the microphone in relation to the wind turbine. Below is a figure that is from the IEC 61400-11 standards showing the recommended reference positions to measure from.



<u>Figure 7 Determining Reference Position</u>

5. **Reference Distance:** From the hub of the wind turbine being studied to the point of intercept by the SLM is termed the reference distance. This

will be determined by the equation specified by the IEC standards;

R_o=H+(D/2) were R_o is the reference position for horizontal axis turbines,

H is the hub height from the ground and D is the diameter of the

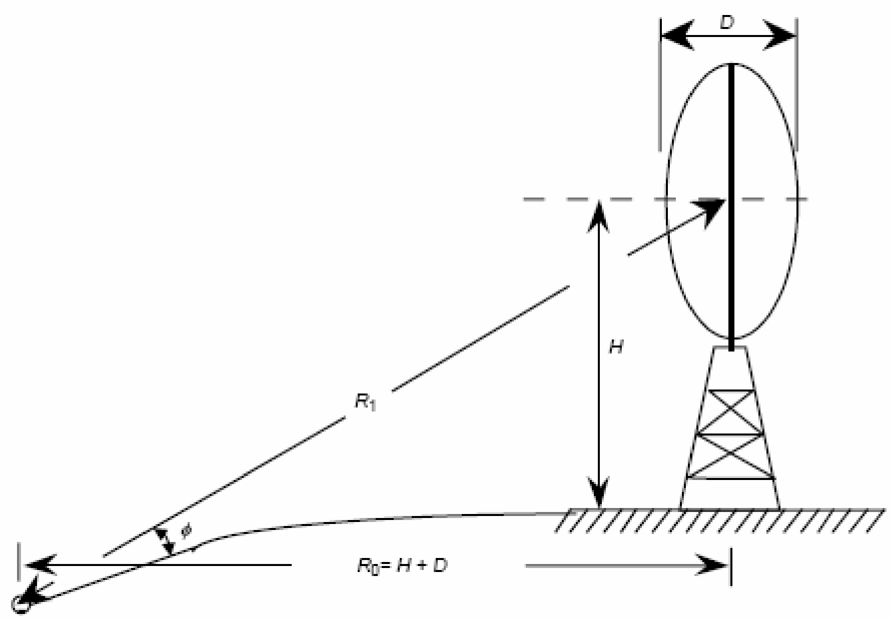


Figure 8 Determining Reference Distance

IEC Measurement Recommendations

Attached is IEC 61400-11 Standards: *Wind turbine generator systems - Part 11: Acoustic noise measurement techniques.* For the research and testing for this project, money is a constraint. For that reason some of the sound analysis (tone, frequency, third octave…) will be omitted from the test results.

IEC Measurements to Report

All measurements and data collected shall be reported in compliance with the IEC 61400-11 standard. See appendix for details. The money constraint limited the purchase of a sound level meter to one that does not measure in 1/3 octaves, nor does it analyze frequency and tonality of sound. Thus in the reported measurements section, it will follow the IEC 61400-11 except for the following: the table and plot of sound pressure spectrum in third octave, identify each tone and frequency of tones. Other then these technical sound analysis measurements the rest of the report for this research paper, *Noise Emitted by Small Wind Turbines*, will follow the IEC 61400-11 standards and procedures for measuring and testing wind turbine generated acoustics.

Chapter 4

Analysis of Data

The testing of acoustic emissions for this project took place at the research and demonstration site on Beech Mountain, North Carolina during the month of November. On this small wind research site there are six wind turbines. My research was limited by mechanical and electrical difficulties occurring, rendering some of the turbines inoperable during the time of testing. For these reasons my research was focused on three small wind turbines, a Bergey XL.1, an African Wind Power (AWP) 3.6, and a South West Wind Power Whisper 175. Close in size, output and rotational speeds, these wind turbines made a good group of small wind machines to study and compare. When comparing small wind turbines, a close look at certain characteristics should be taken in order to analyze and decipher differences and reasons for those differences.

Turbines Tested for Acoustic Emissions

The **Bergey XL.**1 is the smallest of all the turbines tested. It has a rated out put of 1 KW at a rated wind speed of 24.6 MPH. It has a rotor diameter of 8.2 feet and is mounted on a 104 foot guyed tilt-up tower by NRG. Its three blades are made of pulled true carbon reinforced composite.

The **AWP 3.6** is the next largest wind turbine studied for acoustic emissions. At a rated speed of 25 MPH this wind turbine puts out 1.5 KW of wild A/C. The rotor diameter is 11.8 feet and the three blades are made of a composite covered wood. This tough wind turbine is mounted on an Abundant Renewable Energy (ARE) 106 foot guyed tilt-up tower.

The **Whisper 175** is the largest of the three wind turbines tested. With a rotor diameter of 15 feet, this wind turbine puts out 3.2 KW at a rated speed of 27 MPH. This turbine varies in design from the other two turbines studied by having a two blade rotor design rather than a three blade rotor design. This creates a more rhythmic thumping sound to study. The 70 foot tall guyed tilt-up tower from South West Wind Power is a beefy design utilizing a 5 inch schedule 40 steel pipe.

Data Collecting Process

Because of the financial limitations on this research project, the measuring equipment was not up to the IEC standards. The sound level meter used was a type II, which is a general precision grade rather than the Type I precision grade called for by the IEC standards. Also a Wind Explorer data logger was used to collect wind speed data. This data logger collects on ten minute averages only, and can not be set to the one minute average data collecting that is called for by the IEC standards. Because of the limitations posed by the testing equipment, I adjusted my testing procedures to fit the equipment in a way to gather data with what I had to work with, the method that was used was to record instantaneous measurements.

Taking instantaneous measurements requires two people. First the wind direction is established and the reference point to measure from is established by the wind direction and distance from the base of the tower using a tape measure. At this point of reference, the sound board is laid flat on the ground with the SLM laid in the center pointing toward the base of the tower. After the wind speed data logger is wired up at the base of the tower, measurements are ready to be take.

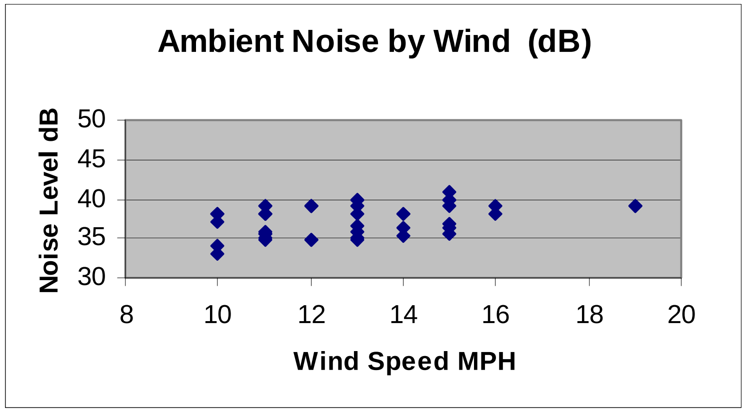
Measurements are obtained from the data logger’s digital display as a present wind speed in MPH. The SLM also has a digital readout that displays the current decibel level. The person reading the SLM watches the display on the SLM till the sound level holds steady then raises their hand to signal the person at the base of the tower to take a measurement of the present wind speed. This method is called instantaneous measurements. As the measurements are called out, the person reading the SLM records the numerical data by hand on a piece of paper kept on hand.

Data Conversion

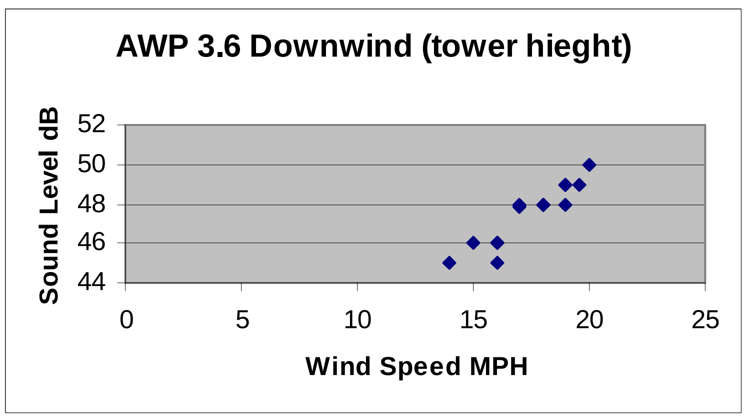
The data collected out in the field with paper and pencil is then brought back and put into the computer. I used Microsoft Excel spreadsheet for all data analysis. The spreadsheet lends the advantage of being able to group data by date collected, location, distance, wind speed and decibel level.

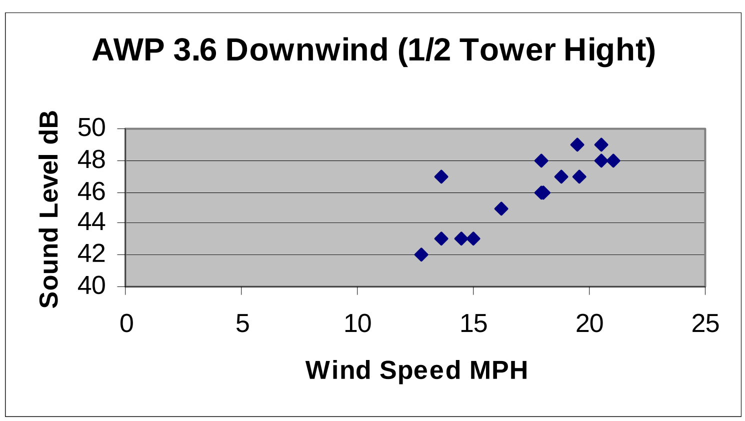
Analysis of Data and Findings

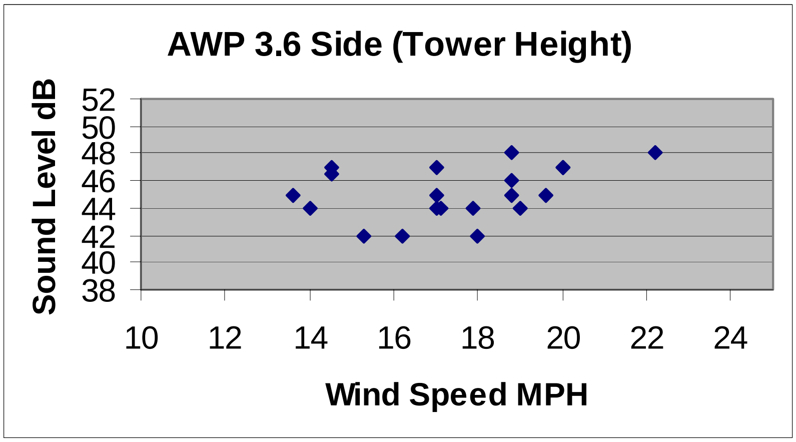
The first thing when studying the noise emitted by small wind turbines is to study the ambient noise in the area. For this site, there is a road that runs on two sides of the property, a few houses, and even some occasional residential construction that takes place well with in ear range of the testing site. The ambient wind noise was take on two different days and combined for a wider range of noise and wind speed. These measurements were taken when there was only wind in the trees and local residential sounds (HVAC…), not during times of construction noise. Below is a graph showing the ambient noise in the area.



After the ambient noise is established, a series of recording sessions take place recording the sound level in decibels from certain distances from the tower and certain reference positions according to which direction the wind is blowing from. Below are two graphs created from the data collected on the AWP 3.6.

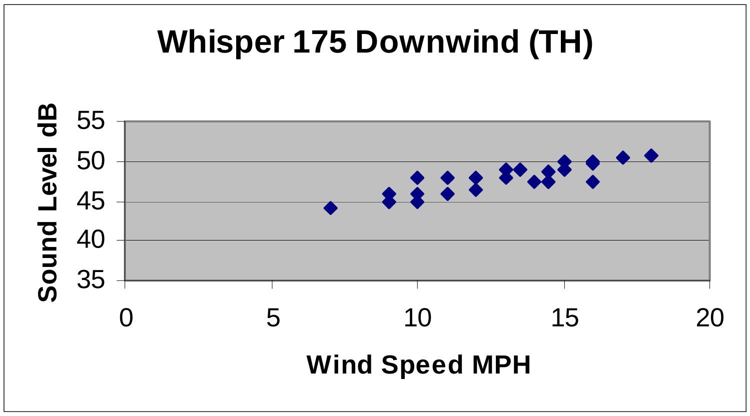


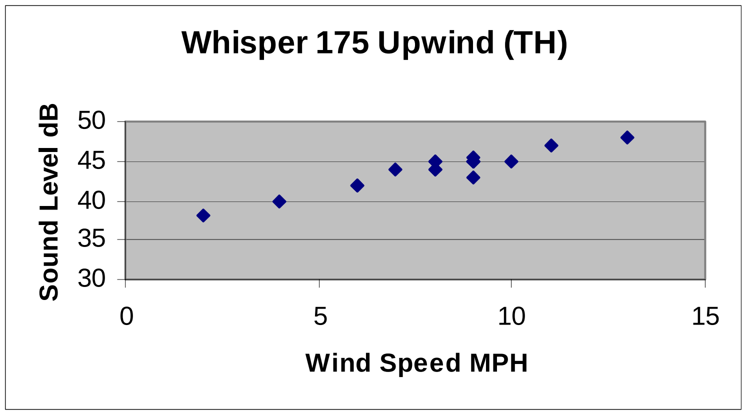




Interestingly enough, the data shows that the measurements taken at the tower height downwind was louder than the measurements taken at ½ the tower height. This means that the loudest place to hear the turbine is at full tower height. In the last graph, recordings taken from the side of the turbine at tower height, the sound level is lower than that taken from downwind. Also notice how this is not the nice clean scatter plot, this is because of background noises that can be seen in the points plotted in the top left portion of the graph showing the data from the side reference point. Also the slope of the line is fairly steep in all three of these graphs for the AWP 3.6, in other words, the level of noise emitted raises rapidly with an increase in wind speed. The noise emitted by the AWP 3.6 is aerodynamic noise.

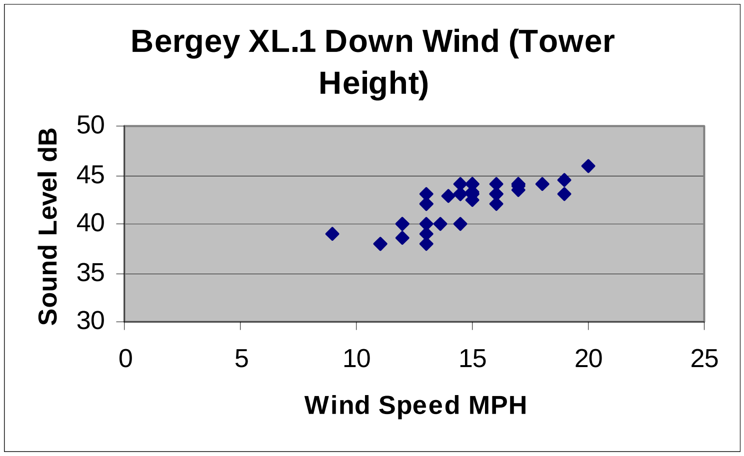
The Whisper 175 was definitely the loudest of the three turbines tested. Below are some graphs of the data collected.

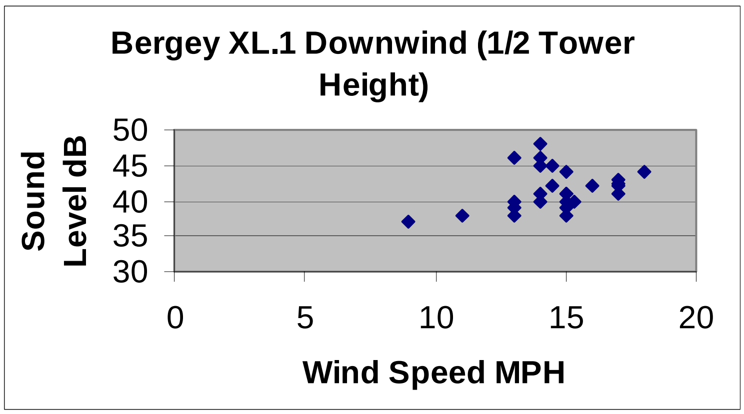


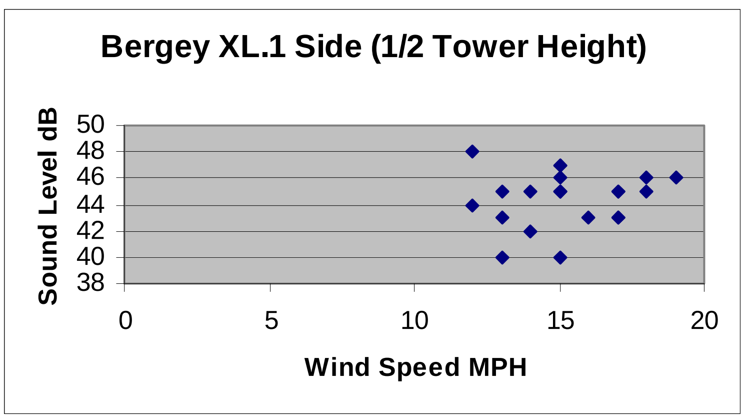


The upper graph shows a nice tight and linear relationship between the increase in sound level and the increase in the wind speed. The sound level produced by the 175 is much higher than that of the AWP 3.6 at comparable wind speeds. Also an interesting finding is that the reference position of the SLM is important to note in comparing the two graphs above. Notice that the sound level is higher at the downwind position and lower at the upwind position at comparable wind speeds. This once again proves that the loudest place to hear a wind turbine is downwind at full tower height. The noise emitted by the Whisper 175 is aerodynamic noise produced by the rotation of the blades.

The Bergey XL.1 is the quietest of the three wind turbines studied. Note that has the smallest rotor diameter and is has the lowest output of the tested turbines as well. Below are some graphs of the data collected on the Bergey XL.1







From first look at the Bergey XL.1 graphs, one can see that this turbine is much quieter than the other two turbines studied. However, besides the obvious differences there is more than just aerodynamic noise. There is mechanical noise very prevalent at wind speeds from 12-16 MPH. This mechanical noise originates from the vibration from the rotation of the blades that is then radiated through out the entire structure of the tower. Notice the rise and widening of the scatter plot at wind speeds between 12-16 MPH. These wind speeds create just the right rotor speed that produces this vibration causing a harmonic hum to resound from the tower structure. Notice how these mechanical noises in the tower are much louder and more pronounced the closer to the base of the tower the reference point is. Evidently the NRG tower used for this particular turbine is not working well to keep this turbine at a low volume.

This set of data on the acoustic emissions from the three small wind turbines was collected by Adam Sacora over a two week period.

Chapter 5

Findings, Conclusions and Recommendations

Using the instantaneous recording method, the level of precision is not quite as accurate as using a method such as one minute averages on both the sound level and wind speed. However, the data collected in this experiment is consistent. This consistency is the strong point for using the data collected from wind turbine to compare it to a different wind turbine.

Findings from Data Analysis and the Bottom Line

From the data collected and presented in this report, it is evident that there is a direct relationship between wind speed and the acoustic emission from a small wind turbine. As the wind speed increases, the noise emitted from the turbine also increases.

It is evident from this study that the noisiest place to hear the acoustics emitted by a small wind turbine is at the tower height downwind of the turbine. Being to the side of the wind turbine, ninety degrees from prominent wind direction, is clearly the quietest reference point to view the noise emitted from a turbine.

From the data collected for this research project, the tower that a turbine is placed on is very relevant to the noise that it emits. If the tower is not sized right for the turbine, the outcome can be very noisy and unattractive to consumers, home owners and neighbors. The tower must be appropriate for the turbine that is supports.

Of the three wind turbines studied, the Whisper 175 is definitely the loudest. The two blade design creates a “whomp whomp whomp” sort of rhythmic acoustic emission, and the large swept area means there is a large amount of atmospheric disturbance creating aerodynamic noise.

The AWP 3.6 was a not as loud as the Whisper 175. With a three blade design and a smaller swept area, there is not so much of the rhythmic thumping of the blades passing through the atmosphere. However, it seems that the amount of increase in sound level per unit of wind speed seems higher than the other turbines, creating a steep sloping relationship between the noise emitted and the wind speed.

The Bergey XL.1 is by far the quietest of the three turbines tested. This is attributed to the small swept area and the three blade design. Interestingly, the harmonic hum caused by vibration in the tower made this turbine the loudest in some wind speeds. This problem can be corrected by proper sizing of the tower to the turbine.

Conclusion

The acoustic emissions from a wind turbine can be attributed to many things. It can come from many sources such as aerodynamics, mechanical or operation of the self-braking characteristics of the turbine its self. It can be enhanced or reflected by such things as rocks, dirt, buildings, structures and even the direction of the wind. The noise can be absorbed by many elements such as air density, humidity, grass, trees and other landscape. It can be drown out be background noise such as a HVAC system, traffic, construction, or even the wind through the trees.

Given the constraints of money, equipment limitations and time dead lines, this research, testing and analysis of acoustic emissions from small wind turbines has been very successful. The data is very useful for comparing the noise output of different wind turbines.

From the information presented in this report, it can be concluded that there are several things that can be done to reduce the noise pollution of small wind turbines.

1. Above all, thorough site analysis is the most valuable energy expended when determining the level of disturbance from a small wind turbine. The information gathered can give you clues to decreasing noise emissions. Getting background noises, surroundings, ground characteristics and landscape context can be coupled with a wind speed and wind direction distribution can be used to match a wind turbine with the site to get the optimal performance and least noise emissions possible.
2. Setbacks can be the simplest way to avoid unwanted noise. Keep the turbine a minimum distance from residential areas or other areas in question of noise disturbance.
3. Tests and studies can help to pinpoint what type of noises and where they are coming from. These tests must be uniform and consistent to a standard (IEC standards) in order to be truly useful. This kind of information can be used to help engineers and designers to correct problems, decrease noise and increase efficiencies in small wind turbines.

Recommendations for Further Studies

Time is needed to collect and accumulate a large bank of data. One thing out of the control of the researcher is when the wind will blow. There are many days when the trip to the wind testing site is in vain. You can not control when the wind will blow, so allow time to get data in a range of wind speeds.

Collect data over a large range of wind speeds, including furling wind speeds. The more data collected, the more defined the scatter plot pattern will be. This will verify the data collected. Collecting such a large bank of data will entail being at the wind testing site on many days, weeks, or months. Days when the wind is blowing steady is the best time to measure noise emissions, but that is not always the case. The larger the range the better and more descriptive the data will be.

Use a data logging type of data collecting system. Having the data in an electronic form allows for proper, verifiable data that can be fine tuned and corrected for all variables such as wind shear, temperature, air density, surrounding landscape and topography, tolerance of the data collecting equipment, distance and other things.

Use a one minute average testing procedure rather then the instantaneous method. Besides following the IEC code, this will create more accurate measurements and allow for background noise disturbance.

Large amounts of data must be collected. The more data you have at a wide range of wind speeds from a certain reference point the better. These mass amounts of data will verify itself for quality control.

Over All

This is been a very good research project that has taught me so much in wind technology, sound recording, sound pressure level analysis, multimedia, documentation, manipulating and handling data, and even mathematics. I would recommend this type of research to anyone that is interested in this topic from home owners, to students, to researchers that are not discouraged by overwhelming obstacles, time spent in the field, time spent at a computer, and time spent reading standards, manuals and reports of tests already done. This is a serious issue that needs research and data collected in order to correct the problem.

If noise is not an issue, or does not have to be an issue, then that is one less obstacle to traverse in this clean energy technology transfer.

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