Energy 65 (2014) 596–604

Contents lists available at ScienceDirect

Energy

journal homepage: www.elsevier.com/locate/energy

# Aero-acoustics noise evaluation of H-rotor Darrieus wind turbines

M.H. Mohamed*

*Renewable Energy Lab. of Mechanical Power Engineering Dept., Faculty of Engineering-Mattaria, Helwan University, P.O. 11718, Cairo, Egypt*

ARTICLE INFO

*Article history:*
Received 16 August 2013
Received in revised form
7 November 2013
Accepted 9 November 2013
Available online 8 December 2013

*Keywords:*
Wind energy
Noise
Darrieus turbine
Aerodynamic
CFD

ABSTRACT

The problems aided with wind turbine noise have been one of the more studied environmental influence areas in wind energy engineering. Noise levels can be measured, but, similar to other environmental attentions, the public's perception of the noise impact of wind turbines is in part a subjective determination. The author investigated in this work the aerodynamic acoustics of one type of the VAWT (vertical axis wind turbine) which called Darrieus turbine. Darrieus turbine is suitable to be established within the densely populated city area. Therefore, the noise item is very important to investigate. In this work, Darrieus rotor has been studied numerically and aerodynamically to obtain the generated noise from blades. This work offers a method based on the FW–H (Ffowcs Williams and Hawkings) equations and its integral solutions. Time-accurate solutions can be obtained from URANS (unsteady Reynolds-averaged Navier–Stokes) equations. Blade shape, tip speed ratio and solidity effects have been studied in this work. The results indicated that the higher solidity and higher tip speed ratio rotors are more noisy than the normal turbines.



## 1. Introduction

Wind turbine generators, ranging in size from a few kilowatts to several megawatts, are producing electricity both singly and in wind power stations that involve hundreds of machines. Many installations are in uninhabited areas far from located residences, and therefore there are no visible environmental influences in terms of noise. There is, however, the potential for situations in which the radiated noise can be heard by residents of adjacent neighborhoods, particularly those neighborhoods with low ambient noise levels. Wind turbines noise frequency ranges from low values that sometimes inaudible to higher values in the normal audible range [1]. Although increased distance is advantageous in reducing noise levels, the wind can reinforce noise propagation in certain directions and prevent it in others. A unique feature of wind turbine noise is that it can result from basically continuous periods of daytime and nighttime operation. This is in disparity to the more common aircraft and road traffic noises that vary markedly as a function of time of day. The human ear comprehends loudness as an individual response to the amplitude of sound. At a given sound pressure level, the ear does not sense all frequencies to be of equal loudness. The normal hearing range of the human ear is 20 Hz–20 kHz, while the ear is most sensitive in the 3–4 kHz region [2].

Noise from wind turbines may be classified as aerodynamic or mechanical in origin. Aerodynamic noise components are either narrow-band (containing discrete harmonics) or broadband (random) and are related closely to the geometry of the rotor, its blades, and their aerodynamic flow environments. The low-frequency, narrow-band rotational components typically take place at the blade passage frequency (the rotational speed times the number of blades) and integer multiples of this frequency. Of lesser importance for most configurations are mechanical noise components from the operating bearings, gears, and accessories [3].

## 2. Noise propagation

Wind turbine generated Aerodynamic noise is still a considerable area of research. It is thought that aerodynamic (or aero-acoustic) noise from the blades emerges from a number of different mechanisms that are related to the way in which the flow over the airfoil interacts with the surrounding air. Techniques for prediction of the noise realized by an airfoil are usually based on theoretical principles but use empirically derived components to attain better agreement with what is observed in practice. Research into the reduction of aerodynamic noise from wind turbines has mainly concentrated on the use of serrated trailing edges, different trailing edge and tip shapes, and different airfoil profiles. The environmental aspects of wind turbine noise attach to how it

* Tel.: +20 112 6060 364; fax: +202 2633 2398.
*E-mail addresses:* mohamed_ibrahim07@m-eng.Helwan.edu.eg, moh75202@yahoo.de.

0360-5442/$ – see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.energy.2013.11.031

propagates over the terrain surrounding the wind turbine and to how the noise is interpreted by people. The noise produced by wind turbines is often dashing and tonal, both of which can add to the annoyance factor of the sound. Several standards for calculation of the propagation of the sound are widely used and range from basic calculations that assume hemispherical propagation (see Fig. 1), to complex calculations designed to be done computationally which take into account the influences of terrain shape, barriers, wind speed and direction, atmospheric temperature profile, humidity, and air and ground absorption. A knowledge of the manner in which sound propagates through the atmosphere is basic to the process of predicting the noise fields of single and multiple machines. Although much is known about sound propagation in the atmosphere, the least understood factors are the impacts of distance from various types of sources, the effects of such atmospheric factors as absorption in air and refraction caused by sound speed gradients, and terrain effects. In this paper the author discusses numerically the intensity of the sound waves and the rate of decay of these waves.

## 3. Purpose of the present work

Many analytical and experimental acoustical studies performed the HAWTs (horizontal axis wind turbines). The results indicated that HAWTs with downwind rotors will generate more noise than will those with upwind rotors. This is because an additional noise source in downwind rotors is introduced when the rotating blades interact with the aerodynamic wake of the supporting tower.

The actual annoyance caused by a noise, is often a function of both the nature of the noise itself and a number of physiological factors. Studies conducted in Sweden on the leverages of wind power [4,5] detected a correlation between the general attitude of a person towards wind power and their level of annoyance. For example, a shareholder in a turbine may find the noise from it reassuring rather than annoying, whereas a summer resident who has gone to the countryside seeking peace and quiet would probably find it more of a disturbance. Pederson's [5] found that the most annoying noise heard from wind turbines was a swishing noise, followed by whistling and then pulsating and throbbing noises. It was also noted that the percentage of people annoyed increased as the noise levels increased. Pure wind turbine noise gave very similar annoyance ratings as unmixed highway noise at the same equivalent level, while annoyance by local road traffic noise was significantly higher [6].

Göçmena and özerdema focused on the optimization of six airfoils which are widely used on small scale wind turbines in terms of the noise emission and performance criteria and the numerical computations are performed for a typical 10 kW wind turbine. The main purpose of this optimization process was to decrease the noise emission levels while increasing the aerodynamic performance of a small scale wind turbine by adjusting the shape of the airfoil. The results obtained from the numerical analysis of the optimization process have shown that, the considered commercial airfoils for small scale wind turbines are improved in terms of aero-

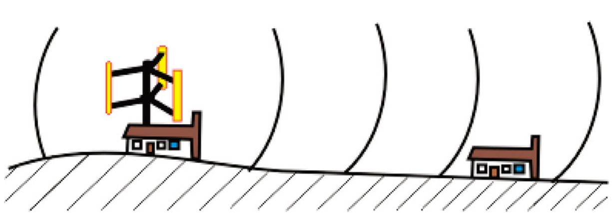

**Fig. 1.** Wind turbine noise propagation.

acoustics and aerodynamics. The pressure sides of the baseline airfoils have been manipulated together with the trailing edge and redesigned airfoils have lower levels of noise emission and higher lift to drag ratios [7].

Obviously, noise is an impact factor that must be treated seriously and adequately, but it is only a secondary factor as far as attitudes are concerned. But it is established clear relations between experimental exposure to turbine noise and perceived annoyance [8,9].

Exploration of survey results showed individuals with a more negative attitude to wind turbines perceive more noise from a turbine located close to their dwelling and those perceiving more noise report increased levels of general symptoms. Individuals' personality also affected attitudes to wind turbines, noise perception from small and micro turbines and symptom reporting [10].

Conversely, the noise conspicuous to a listener could actually be increased under certain conditions. For example in the situation where the wind turbine is on a hill and the receptor site is somewhere at the base of the hill screened from the wind, the wind speed on top of the hill is likely to be 1.5:2 times the wind speed at the receptor site. This would reduce the background noise at the receptor site, and the wind turbine noise would thus appear to be more outstanding [11]. Application to a wind park shows clearly the influence of the terrain on the wind velocity and consequently on the SPL [12].

Rogers and Omer found that a doubling of the turbulence intensity from 0.3 to 0.6 resulted in an almost doubling of the sound energy level [13].

The results emphasized the hypothesis that the spectrum of wind turbine noise moves down in frequency with increasing turbine size. The relative amount of emitted low-frequency noise is higher for large turbines (2.3–3.6 MW) than for small turbines ($\leq$2 MW). The difference is statistically worth for one-third-octave bands in the frequency range 63–250 Hz. The difference can also be expressed as a downward shift of the spectrum of approximately one third of an octave [14]. At high rotational speeds the turbines produce a 'thumping', impulsive sound, increasing annoyance further [15].

The security level observed due to the wind turbine operation tends to increase with the increment of installed capacity. The social risk was calculated (characteristically arbitrary). As observed by the results (the curves in the F–N diagram) obtained for both scenarios, the risk does not exceed the upper limit of ALARP (as low as reasonably practicable) criterion. Nonetheless, the required application of principles for the integration of safety to tackle the hazards linked with wind turbines must not be neglected. Safety must be increased as the wind energy production expands, as well as there should be a need for regular reconsideration [16].

Comparison of the noise from the individual blades shows that the tripped blade is significantly noisier than the other two. Narrowband analysis of the de-dopplerized blade noise spectra indicates that trailing edge bluntness noise is not important. All in all, the test results convincingly show that broadband trailing edge noise is the dominant noise source for this wind turbine [17].

Because very little information on the acoustics of VAWTs (vertical axis wind turbines) is currently available, it is difficult to directly compare the noise generation characteristics of HAWTs and VAWTs [3].

The blades of a VAWT interact with the aerodynamic wake of the rotor's central column in a manner similar to the way that a downwind HAWT rotor interacts with its tower wake, but at a greater distance relative to the column diameter. Thus, the magnitude of the noise from a VAWT rises by this interaction. This is expected to be less than that of an equivalent downwind HAWT rotor and greater than that of an upwind HAWT rotor. There is