NOISE ANALYSIS OF 3-BLADED H-DARRIEUS TURBINE AT DIFFERENT ANGLES OF ATTACK

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Abstract: Different sources of renewable energy are available around us. One of the most suitable and clean renewable energy source is the wind. Vertical-axis wind turbines are insensitive to wind direction variations, that makes this type of wind turbines suitable for installations in urban areas. In the present work, noise levels, for 3 bladed vertical axis turbine (H-Darrieus type) were analyzed for different angles of attack. Turbine blade analyzed was symmetric airfoil (NACA series). Calculations were performed on a 2D model for 10 - 15 m/s inlet velocities. Pressure and velocity fields with noise levels were calculated using RANS method for turbulence modeling. It was found that this approach can reveal the noise sources for this type of turbine in its operational regime. Furthermore, this method can be used in initial stages of turbine design, especially for airfoil selection for noise levels minimization.

Keywords: Vertical-axis wind turbines, aeroacoustic model, noise, angle of attack

1. INTRODUCTION

There is a growing need for energy on a global scale. Alternative energy sources that would primarily replace or lessen the use of fossil fuels as the primary source of energy have long been sought after. This is true not just because the aforementioned fuels have restrictions, but also because this particular fuel type contains significant pollutants that have a harmful impact on the environment. The global energy landscape will change more in the next 10 years than in the past previous hundred. As the global energy sector moves away from fossil fuels and toward renewable energy sources, industrial companies face the challenge of this transition in a transformative way. Hence, What are the alternative energy sources in, the present day?

Alternative energy comes from sources other than fossil fuels, and as a result, it emits little or no greenhouse gases like carbon dioxide (CO2). As a result, energy generated from non-traditional sources does not contribute to the greenhouse effect that is responsible for climate change. Since coal, oil, and natural gas have been the most popular energy sources since the Industrial Revolution, these sources are referred to as "alternative" energy sources. When these fossil fuels are used to create energy and electricity, they release significant amounts of CO2. Although many renewable energy sources can also be categorized as alternative energy, alternative energy should not be mistaken for renewable energy. For instance, solar energy is both renewable and alternative because it is abundant forever and doesn't produce greenhouse gases.

Alternative energy sources include hydroelectric power, solar power, geothermal power, wind power, nuclear power, and biomass power.

Given that it is free, plentiful, and clean, wind energy is a great alternative energy source. Additionally, it is a good choice for the future. In recent years, numerous scientists have been studying how to convert wind energy into mechanical, thermal, electrical, and other kinds of usable energy. In 2010, Iceland used the most energy per person in the entire globe, utilizing the equivalent of 16,842 kilos of oil per person. The majority of that energy is not coming from oil because Iceland gets 85% of its energy from non-oil sources including hydroelectric and geothermal energy.

Based on wind statistics data it can be concluded that the wind energy is available almost everywhere in the world and can be used as a backup energy source. Before proceeding further, brief explanation of how can wind energy be converted into different types of energy is given.

One way to transform the kinetic energy of air currents (wind) into electrical energy is by menas of electro-mechanical systems called wind turbines. Main components of the a typical wind turbine are the rotor, which transforms kinetic energy into mechanical energy, and the generator, which transforms this mechanical energy into electrical energy. Horizontal-axis wind turbines (HAWTs) and vertical-axis wind turbines are the two types of wind turbines (VAWTs). The concept of using wind energy to produce mechanical power has been around for thousands of years. Turbines capture wind energy with propeller-like blades that function similarly to an airplane wing. A pocket of low-pressure air forms on one side of the blade when the wind blows. The blade is then drawn toward the low-pressure air pocket, causing the rotor to turn. This is referred to as a lift. The force of lift is much greater than the force of the wind against the front side of the blade, which is known as drag. The rotor spins like a propeller due to the combination of lift and drag.A series of gears increases the rotation of the rotor from about 18 revolutions per minute to about 1,800 revolutions per minute, allowing the turbine's generator to produce alternating current (AC).

This concept, for a three-bladed vertical wind turbine, is schematically presented in the following picture:

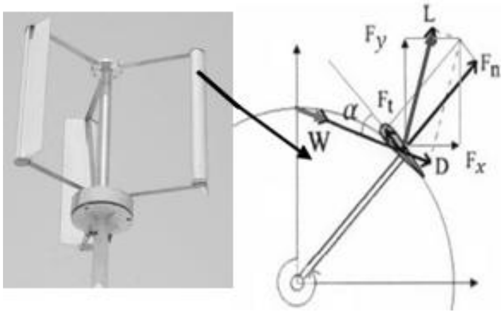

Figure 1. H-Darrieus turbine Force Diagram on leading blade.

As it was pointed in the previous text, wind power is one of the most promising renewable energy sources. However, there are drawbacks to wind turbine technology, one of which is the noise generated during wind turbine operation. Noise can have a negative impact on humans and other living beings. This fact is the main reason why aeroacoustic analysis has to be performed even in the early design stages of wind turbines. Reduction of noise levels produced or even total attenuation if possible is one of the design goals.

To successfully impede or reduce noise, the sources of the noise must be identified. During operation, the two main sources of noise are aerodynamic and mechanical. Mechanical noise is frequently generated by the wind turbine's many different parts, including the generator, hydraulic systems, and gearbox. Mechanical noise can be reduced using a variety of techniques, including vibration isolation and suppression. On the other aerodynamic noise can arise from many parts of the wind turbine, and in the following text, first, the sources of the aerodynamic noise sources are investigated followed by the aeroacoustic analysis methods for noise level predictions.

2. NOISE SOURCES ON WIND TURBINES

Many wind turbine components may produce noise. A great number of variables influence the noise levels generated during wind turbine operation. In general, the noise type on wind turbines is Mechanically generated noise and aerodynamic noise. The main focus of this paper is aerodynamic noise because this type of noise contributes the most to the overall noise levels on wind turbines, and is more complex to analyze and predict to treat.

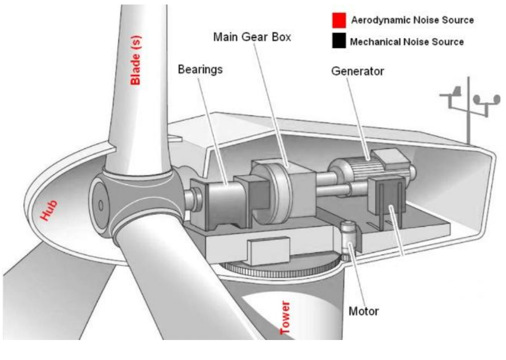

Figure 2. Noise sources (Mechanical and Aerodynamic) on wind turbine.

2.1. Mechanical noise

Hydraulic systems, gearboxes, and generators are the most common sources of mechanical noise. Furthermore, other wind turbine components, such as ducts and inlets can contribute to the overall mechanical wind turbine noise levels. Mentioned wind turbine mechanical parts tend to produce tonal, narrowband sort of noise, which is unpleasant to humans when compared to broadband sound.

Mechanical noise is transmitted through the structural components of the wind turbine. structure and then be dispersed into the environment via a variety of surfaces, including the rotor blades, nacelle cover, casing, and the tower.

2.1. Aerodynamic noise

Aerodynamic noise is more complex to analyze, and as shown in Figure 3, it is the most common source of noise from wind turbines.

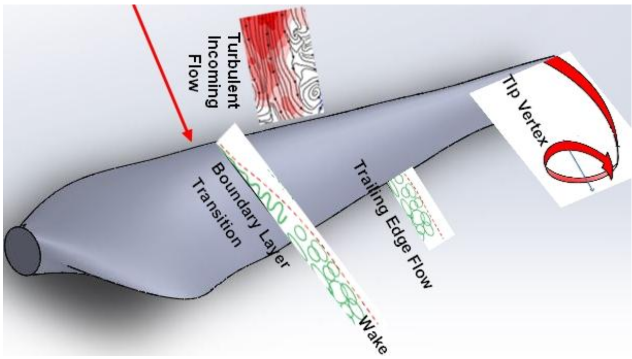

Figure 3 Aerodynamic noise sources.

There are six major regions along the blade in general (see Figure 3) that are considered critical regions for aerodynamic noise generation. These regions generate their own diverse noises since they occur in different regions on the wind turbine blade. Aerodynamic noise , generated on the wind turbine blade, can be classified into following types: Separation stall noise, Turbulent boundary layer trailing edge noise, laminar boundary layer vortex shedding noise, trailing edge bluntness vortex shedding noise, tip vortex formation noise, and noise due to turbulent inflow.

As shown in Figure 3, turbulent boundary layer trailing edge noise results from the interaction of the boundary layer and the trailing. It is possible that the turbulent boundary layer trailing edge noise occurs on both the lower and the upper side of the airfoil. This type of aerodynamic noise is mostly influenced by the Reynolds number and blade angle of attack, which is analyzed in this paper.

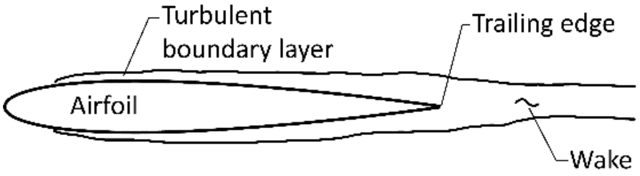

Figure 4. Turbulent boundary layer trailing edge noise [1].

As shown in Figure 4, separation-stall noise occurs as the angle of attack increases. This type of noise is more prominent at higher angles of attack.

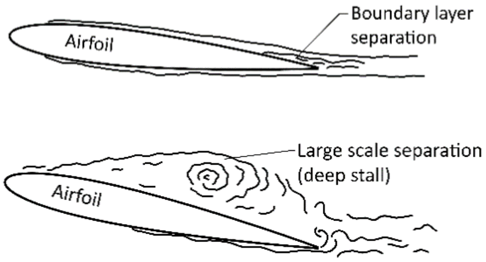

Figure 5. Separation-stall noise [1].

Another type of noise occurs when a laminar boundary layer is present over most of the airfoil. This is illustrated in the following Figure.

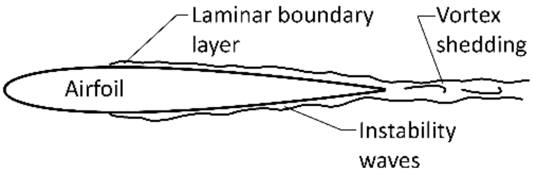

Figure 6. Laminar-boundary-layer vortex shedding noise [1].

An important source of noise is noise caused by vortex shedding from blunt trailing edges, as shown in Figure 7. The geometry of the trailing edge itself affects the frequency and amplitude of this noise type. Vortex shedding noise is calculated using empirical relationships for predicting noise levels arising from vortex shedding and they are dependent on the trailing edge thickness.

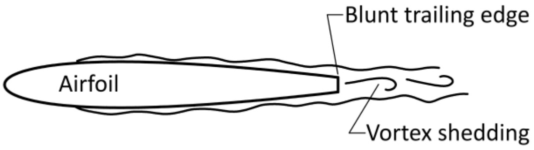

Figure 7. Trailing-edge-bluntness vortex-shedding noise [1].

The interaction of the turbulent inflow with the leading edge of the turbine blades is another noise source, especially at low frequencies. Additional information regarding noise generation on wind turbine blades can be found in [1-10].

3. NUMERICAL PROCEDURE

3.1. Computational domain and mesh

Computational domain of the problem that is being considered in this paper is presented in Fig. 8. This is a 2D case of a three bladed H-Darreius vertical axis wind turbine. The airfoils of the turbine are NACA 63-215.

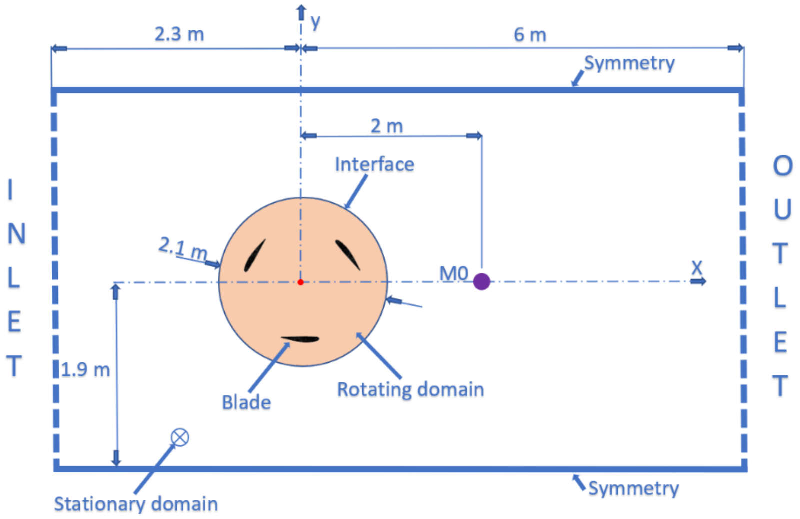

Figure 8. Computational domain.

Airfoil cord length is set to 0.33 m, with a rotor radius of 0.75 m. The diameter of the rotating part of the domain is 2.1 m. This part of the domain is connected to a stationary part via sliding interface boundary condition that conserves both mass and momentum. The computational domain extends 2.3 m and 6 m from the turbine's center upstream and downstream, respectfully, and 1.9 m laterally to either side of the turbine. Sound pressure levels are calculated using the Ffowcs Williams and Hawkings (FW-H) equation for reciver placed in location presented in Figure 8 as M0.

The unstructured mesh is applied for the whole domain. Finer mesh is used around the blades in order to capture the flow more accurately. Figure 9 presents the mesh of the whole computational domain and a detail around one of the blades. Since we have used k-ε turbulence model, care is taken that the y+ value is approximately 30 near all the walls.

3.2. Boundary condition and solver set-up

Boundary conditions are set as follows: On the top and bottom of the domain a symmetry boundary condition is set. Uniform velocity on the inlet (10 m/s and 15 m/s) and uniform pressure on the outlet boundary are set. The no-slip boundary condition is set on the airfoils. To simulate the rotation of the turbine, the central part of the mesh was allowed to move relative to the outer fixed domain (green in Fig. 9). An interface wall is introduced between the rotating and fixed parts of the domain. We have set the rotational velocity of the turbine to 6 rad/s.

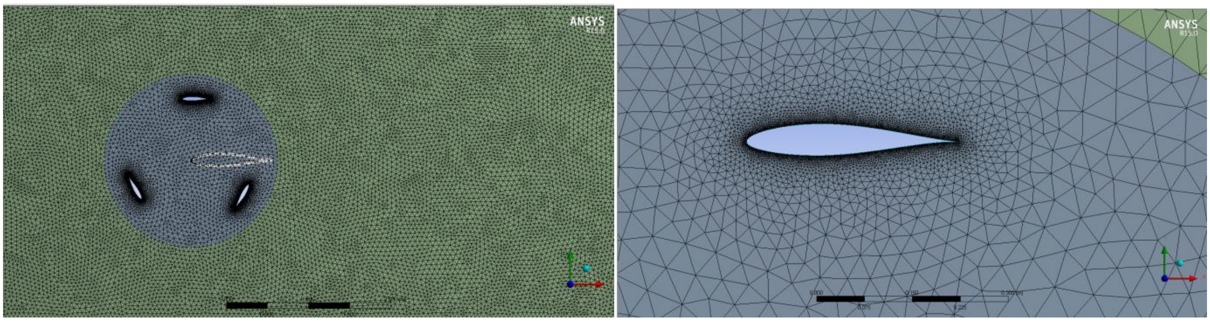

Figure 9. Mesh of the computational domain with detail around the airfoil on the right.

Transient calculations are performed in Ansys software, using SIMPLE algorithm for pressure-momentum equations coupling. Discretization of momentum and pressure fields is performed with second order schems, while turbulent quantites equations are discretizised with first order schemes. Tolerances for matrix solvers are set to 10^{-5}.

4. RESULTS AND DISCUSSION

Figure 10 presents the pressure fields in the two cases considered: for inlet velocity of 10 m/s and 15 m/s. It is evident that the pressure values are higher in the case with the higher value of the inlet velocity. The vortex shedding is present in both cases, as expected. However, the vortices have more energy in the later case.

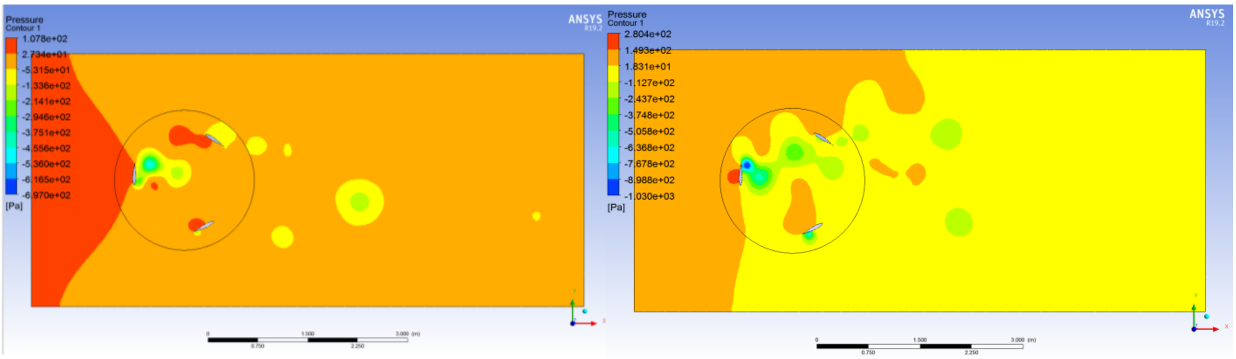

Figure 10. Pressure fields in the case of inlet velocity a) 10 m/s, b) 15 m/s.

Corresponding sound pressure levels are presented in Figure 11. For lower inlet velocity a higher sound pressure level is achieved, and it becomes constant faster than the one for greater inlet velocity. This is normal having in mind the distance between the microphone and the wind turbine.

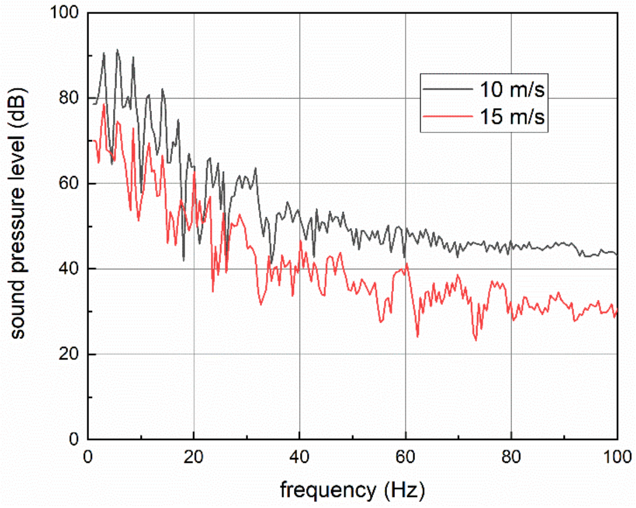

Figure 11. Sound pressure levels for two inlet velocities.

Figure 12 presents the influence of a single wind turbine's blade in a certain position on the sound pressure level presented in Figure 11. The position of the blade is defined with the azimuth angle. We have considered three azimuth angles on this occasion: 0^o, 30^o and 90^o.

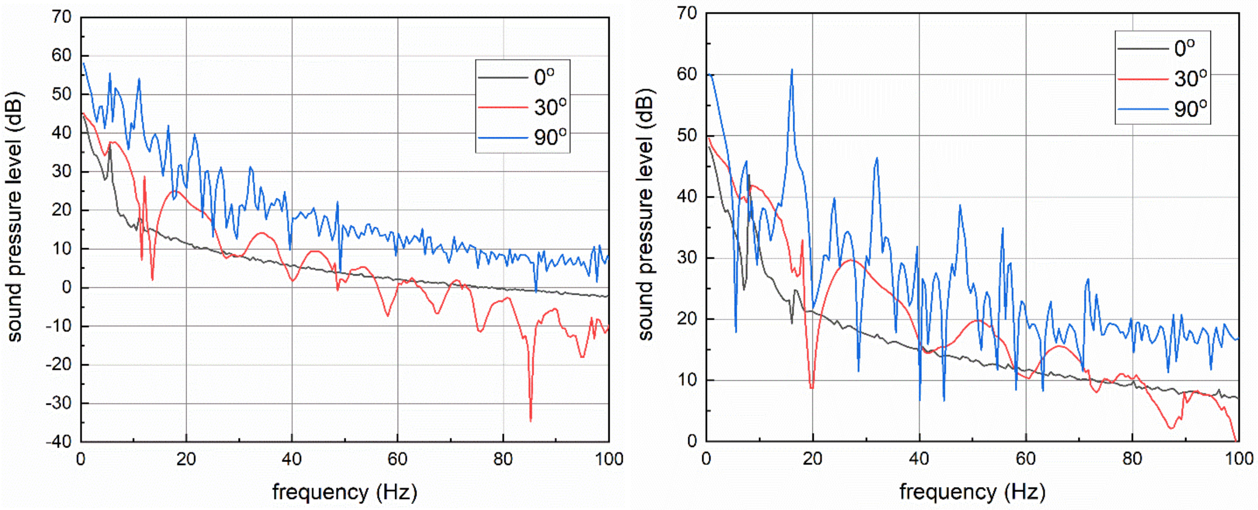

Figure 12. Sound pressure levels for azimuth angles 0, 30 and 90 and inlet velocity 10 m/s (on the left) and 15 m/s (on the right).

Diagrams in Figure 12 demonstrate that the position of the blade in the wind plays and important role in its contribution to the noise production, as we have disscused earlier. The blade that is its most aerodynamic position (0^o) produces noise whose sound pressure level is more or less without any fluctuations. However, for two different angles of attack (30^o and 90^o), sound pressure levels are quite unstable. What is expected, the blade position defined with azimuth angle of 90^o is the most unfavorable for noise production.

5. CONCLUSIONS

This paper discusses the posibility of determination of noise production levels based on a position of a single blade of a vertical axis wind turbine. Different sources of aerodynamic noise are disscussed in the paper. A 2D computations of a wind turbine operation are performed for different wind velocities. It is confirmed that blade position in wind is important in the wind turbine noise production. This methodology can be used for noise production analysis of different airfoils used for blade construction. However, for more detail analysis a 3D calculations are in order.

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ANALIZA BUKE H-DARIEUS TURBINE SA 3 LOPATICE POD RAZLIČITIM NAPADNIM UGLOVIMA

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Apstrakt: Oko nas su dostupni različiti izvori obnovljive energije. Jedan od najprikladnijih i najčistijih obnovljivih izvora energije je vetar. Vetroturbine sa vertikalnom osom su neosetljive na varijacije smera vetra, što čini ovaj tip vetroturbina pogodnim za instalacije u urbanim sredinama. U ovom radu analizirani su nivoi buke za vertikalnu vetroturbinu sa 3 lopatice (H-Darrieus tip) za različite napadne uglove. Analizirana lopatica turbine je bila simetričan aeroprofil (NACA serija). Proračuni su izvršeni na 2D modelu za ulazne brzine 10 - 15 m/s. Polja pritiska i brzine sa nivoima buke izračunata su primenom RANS metode za modeliranje turbulencije. Utvrđeno je da se ovim pristupom mogu otkriti izvori buke za ovu vrstu turbine u njenom režimu rada. Štaviše, ovaj metod se može koristiti u početnim fazama projektovanja turbine, posebno za izbor aeroprofila za minimiziranje nivoa buke.

Ključne reči: vertikalna vertoturbina, aeroakustični model, buka, napadni ugao