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Research paper

Aerodynamics and Modal Analysis for the Combined Vane type Vertical Axis Wind Turbine

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Abstract

The present global energy economy suggests the use of renewable sources such as solar, wind, and biomass to produce the required power. The vertical axis wind turbine is one of wind power applications. Usually, when the vertical axis wind turbine blades are designed from the airfoil, the starting torque problem begins. The main objective of this research is to numerically simulate the combination of movable vanes of a flat plate with the airfoil in a single blade configuration to solve the starting torque problem. CFD analysis in ANSYS-FLUENT and structural analysis in ANSYS of combined blade vertical axis wind turbine rotor has been undertaken. The first simulation is carried out to investigations the aerodynamic characteristic of the turbine by using the finite volume method. While the second simulation is carried out with finite element method for the modal analysis to find the natural frequencies and the mode shape in order to avoid extreme vibration and turbine failure, the natural frequencies, and their corresponding mode shapes are studied and the results were presented with damping and without damping for four selected cases. The predicted results show that the static pressure drop across the blade increase in the active blade side because of the vanes are fully closed and decrease in the negative side because of the all the vanes are fully open. The combined blade helps to increase turbine rotation and so, thus, the power of the turbine increases. While the modal results show that until the 5th natural frequency the effect of damping can be neglected. The predicted results show agreement with those reported in the literature for VAWT with different blade designs.

Keywords: *Renewable Energy, Wind energy, VAWT, CFD, Modal Analysis, Mode Shapes.*

1. Introduction

Wind energy in the last few years has been considered one of the most viable options in the search for renewable energy sources. In the few coming decades, wind energy is going to be among the largest power supply and in the lead for the renewable energy. A wind turbine is the one of the most wind power applications, its used as a machine for converting the kinetic energy available in the wind into mechanical energy which is then used to grinding grain, pumping water and produce electricity. The wind turbine can be divided into Horizontal Axis Wind Turbines (HAWTs) and Vertical Axis Wind Turbine (VAWTs) two categories by the different rotor shaft. (VAWT) is widely used nowadays, the main advantage is that the gearbox and the generator are located near the ground and it doesn't need to direct the turbine toward the wind that's meaning it can be used in areas of varying wind speeds. Many wind turbine researchers they are focused on accurately predicting wind turbine efficiency. (Kacprzak et al., 2013) Studied the CFD analysis for different Savonius rotors design likes Classical Savonius, Bach-type one and Elliptical rotors using ANSYS CFX. (Kadhim et al., 2016) simulated numerically three and four blade vane type vertical axis wind turbine (VVAWT) with different blade shape under movable vanes conditions to investigate its aerodynamic performance.

The optimal design of a turbine is dependent on reducing vibrations, which can be done by accurately identifying turbine's natural frequencies and mode shapes (Griffith et al., 2008). (Saddam et al., 2015) Modeled and analyzed the NACA 0018 airfoil for a straight three-blade rotor of a vertical axis wind turbine. ANSYS-FLUENT is used for CFD analysis, while ANSYS is used for structural. The blades are twisted and fabricated from fiber reinforced composite materials to reduce the rotor weight. They are investigated that the stress values are significantly increased for the rotor with twisted models compared to the straight model. By determining the modes of the wind turbine, it can be ensured that the turbine's operational conditions preclude resonant frequencies, thereby minimizing dynamic loads and lengthening the life of the turbine (Bir and Jonkman, 2008). Modal tests can be conducted with the turbine in a parked position or in rotational operation. In the frequency-domain analysis of floating VAWTs, the aerodynamic damping should be included to provide more reasonable motion and structural responses and give a more accurate estimation of fatigue damage. (Zhengshun, et al., 2016). The proximity of wind and wave load frequencies to an offshore wind turbine (OWT) natural frequency necessitates a thorough examination of different sources of damping e aerodynamic, hydrodynamic, structural, and soil damping e in order to reduce design loads and improve offshore wind energy economics (Carswell, et al., 2015).

2. Problem Statement

The main problem with Darrieus type VAWT its low starting torque. Movable vanes of a flat plate shape are added to the helical airfoil Darrieus turbine to increase the starting torque. Another problem with the VAWT is the noise and extreme vibration, which can be reduced by studying the model characteristics of the turbine.

The Aim of Research

The main goal of this research is to simulate numerically the aerodynamics characteristic and the eight natural frequencies with their corresponding mode shapes for the vertical axis wind turbine has combined vane of the flat plate (having three movable vanes) and the Darrieus helical airfoil.

3. Method of Research

Computational Fluid Dynamics (CFD) with Finite volume method was performed to obtain the aerodynamics characteristic for the combined vane type of flat plate (having three movable vanes) with the Darrieus helical airfoil. The Shear Stress Transport (SST), the k-ω turbulence model is used in this simulation. Figure (1) shows the design of the helical airfoil. The type of airfoil is used in the present study is NACA 0012 and the characteristic geometry of the airfoil are Height (h = 100 mm), Chord (c = 40 mm), Thickness (t = 4.8 mm), Angle of twist (Ø = 60o). Figure (1) shows the combined blade vertical axis wind turbine. Each blade has three movable vanes.

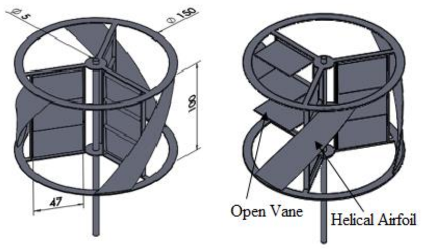

Figure 1. Model design, (a) closed vanes at 90° angular positions, (b) open vanes at 120° angular positions.

The modal analysis was used to find the natural frequencies and mode shapes of a (VAWT). The natural frequencies and mode shapes are important characteristics in the design of a structure of the dynamic loading situation. They are also required if a spectrum analysis or a mode superposition harmonic or transient analysis.
A modal analysis of a pre-stressed structure can be performed, such as a spinning turbine blade. Another useful feature is modal cyclic symmetry, which allows you to review the mode shapes of a cyclically symmetric structure by modeling just a sector of it.

4. Analysis and Discussion

Figure 2 shows, the Contours of static pressure distribution on surfaces of three blade turbine at angular positions 270° to represent the case of all vane are fully open. At this position, the air can flow freely between the vanes and the turbine will rotate faster.
Figure 3 shows the contour of static pressure distribution in and around for three combined vertical axis wind turbine at 270° angular positions when the vanes are fully opened. From the contour, it can be clearly seen that the positive pressure on the frontal surface of the blades in front of the air stream, and a negative pressure on the other sides of the back surface of the blades.
Figure 4 shows the velocity contours at 90° blade angular positions in case of closed vanes, and at 270° blade angular positions in case of open vanes. From Figure 4 it can be seen that the flow of air passes through the blade freely because all vanes are opened and thus, there's no resistance to the flow on this side.

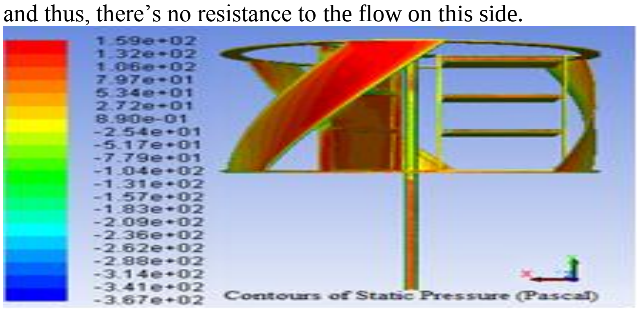

Figure 2. Static Pressure Contours on blades surfaces at angular positions 270°.

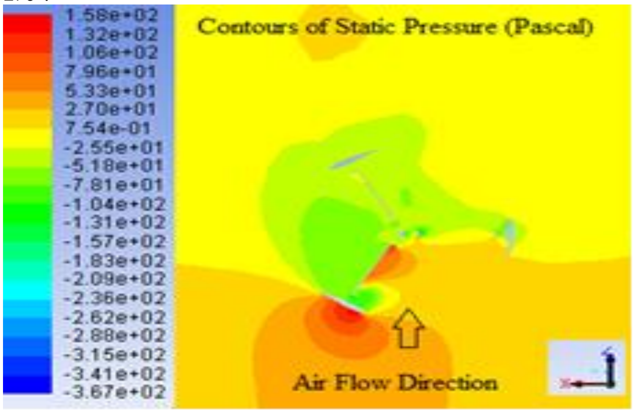

Figure 3. Static pressure contours around turbine blades at angular positions 270°.

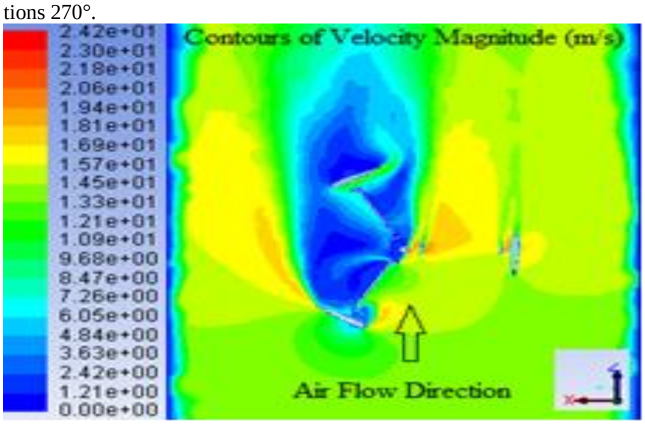

Figure 4. Contours of velocity around turbine blades at angular positions 270°.

As stated earlier the modal analysis was done to establish up to the (8th) natural frequencies with their corresponding mode shapes. Damping was ignored in the first set of simulation and was considered in the second set.
The maximum displacement, on the other hand, showed a different trend. It begins similarly but after reaching the 5th frequency a jump can be seen in Figures (5) and (6) after that the behavior returned to the normal variation, this is an interesting aspect and needs for further investigation.
A similar trend was observed for the corresponding mode shape in the two cases (with and without damping). Also by comparing the frequencies in both cases, it was found that they were identical until the 5th natural frequency as can be seen in Figure (5) with a percentage difference of up to 3.7% in the 8th frequency. This gives an indication that the damping can be neglected up to the 5th frequency without any effect on the analysis. As it was stated earlier that the modal is the first step and many steps may follow, like harmonic analysis. Figures (7 to 10), show the mode shapes of the (VAWT) without damping, while figures (11 to 14), show the mode shapes when damping is considered in the analysis.

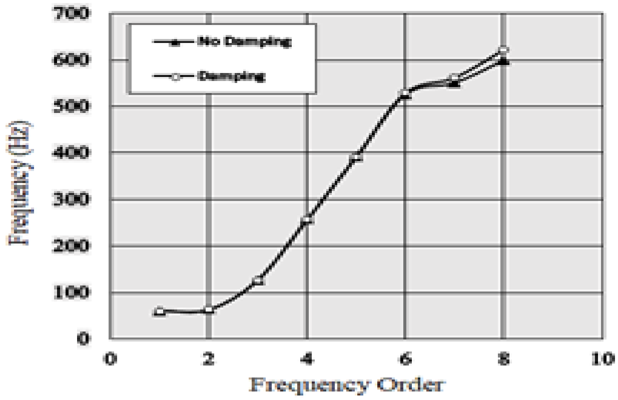

Figure 5. Frequencies Comparison

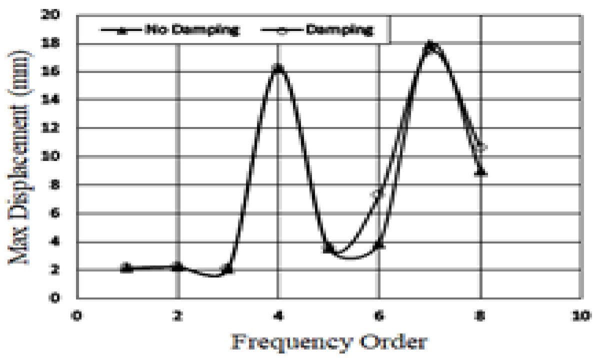

Figure 6. Maximum Displacement Comparison

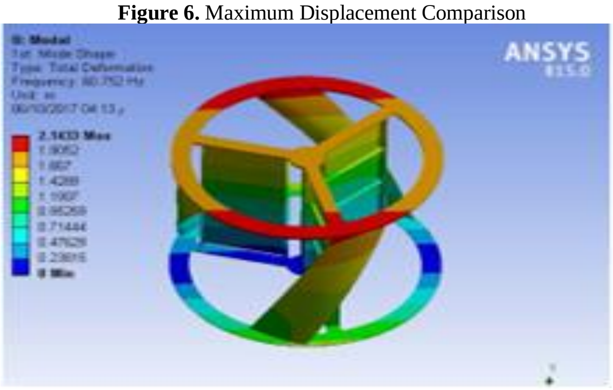

Figure 7. Mode Shape (1) without Damping at Frequency of 60.75[Hz.]

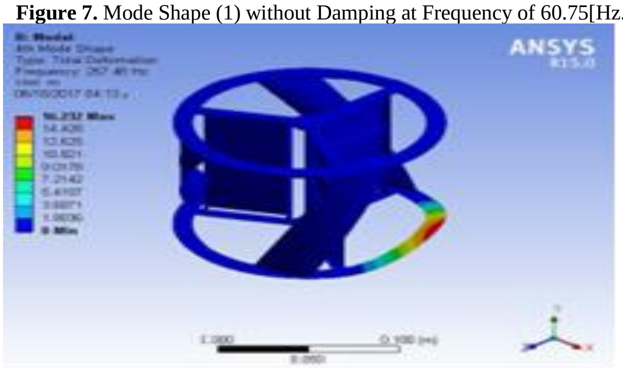

Figure 8. Mode Shape (2) without Damping at Frequency of 257.48[Hz.]

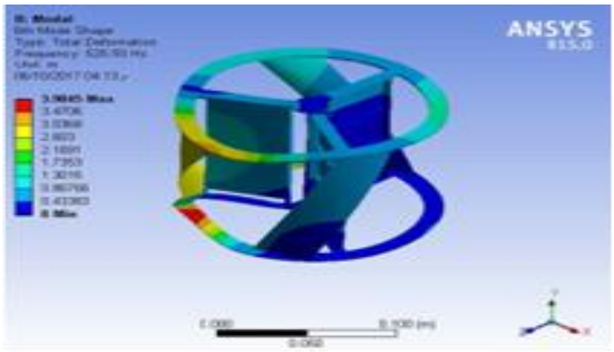

Figure 9. Mode Shape (3) without Damping at Frequency of 525.93[Hz.]

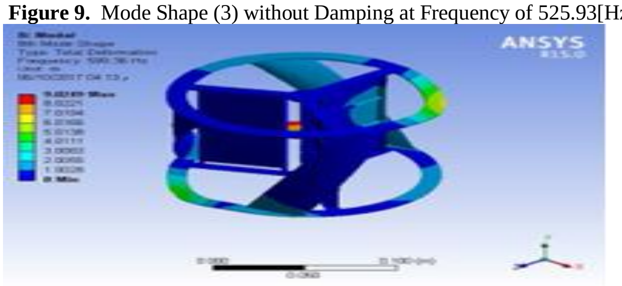

Figure 10. Mode Shape (4) without Damping at Frequency of 599.36[Hz.]

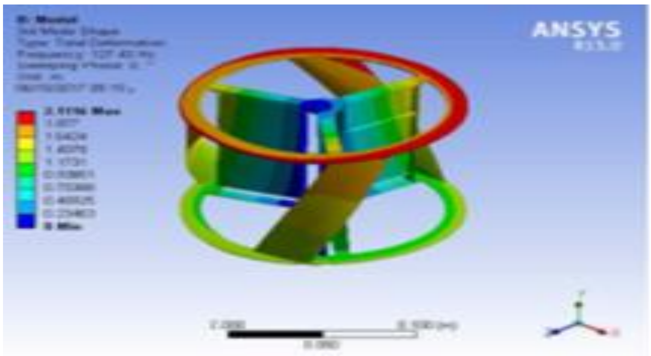

Figure 11: Mode Shape (1) with Damping at Frequency of 60.75[Hz.]

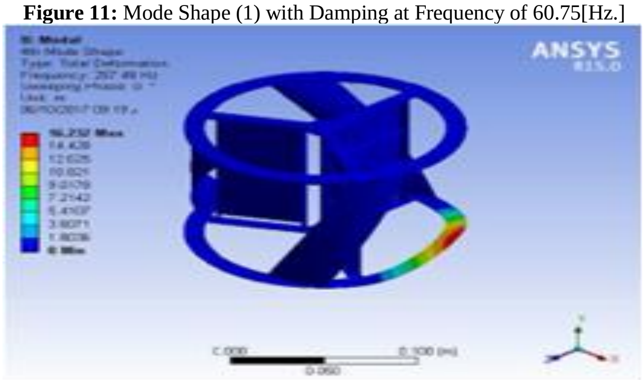

Figure 12. Mode Shape (2) with Damping at Frequency of 257.48[Hz.]

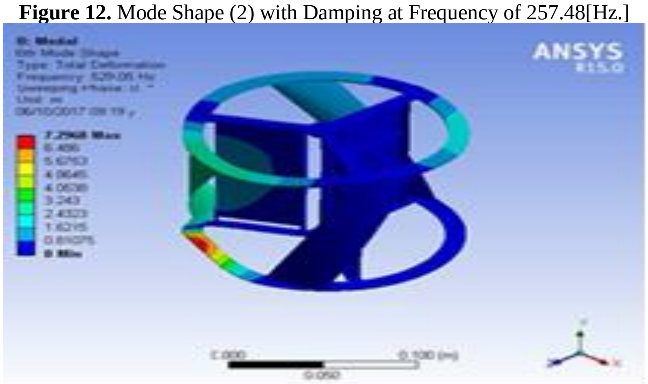

Figure 13. Mode Shape (3) with Damping at Frequency of 529.05[Hz.]

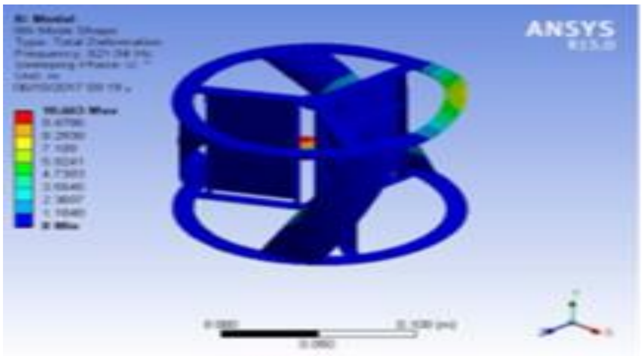

Figure 14. Mode Shape (4) with Damping at Frequency of 621.94[Hz.].

5. Conclusion

The following conclusions can be derived from this work:
1. The static pressure drop decreases when blade rotates to the negative side and this helps to increase turbine power. The flow of air passes through the combined blade at the negative side when all the vanes are freely open. This case helps to increase turbine rotation and so the power of the turbine increased.
2. Comparing the frequencies in both cases, it was found that they were identical to the 5th natural frequency with a percentage difference of up to 3.7% in the 8th frequency.
3. The maximum displacement showed a large jump at the 5th mode shape in the damping case which further investigations.

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