

The impact of the number and materials of the blades on the computational and fluid dynamics study of a vertical axis wind turbine

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ABSTRACT

Among the many different non-traditional methods of producing power, wind has shown to be a successful alternative energy source. The geographical features of our region will allow the vertical axis windmill to produce electricity efficiently. Wind energy is converted into more useful forms through the usage of wind turbines. An electrical generator, which transforms the motion of turbine blades into electrical current, is used to convert the majority of wind power produced in the modern period into electrical power. Windmills use mechanical machinery powered by wind energy to carry out physical activities like breaking grain or pumping water. Applications for wind energy include both large-scale wind farms that power entire nations' electrical networks and small freestanding turbines that power remote rural settlements. By increasing the number of blades from three to six and changing the materials (PVC and Carbon Fiber), this article investigates the efficiency of VAWT. Additionally examined are the blades' deformation and stress distribution for both materials.

Key words; Wind Blade, PVC, Carbon Fiber, CAD Model, CFD

INTRODUCTION

Most wind energy research over the past few decades has centered on horizontal-axis wind turbines (HAWTs), the dominant technology in current power grids. However, research into vertical-axis wind turbines (VAWTs) has continued on a smaller scale, yielding diverse designs. Evidence indicates that VAWTs offer a viable alternative in turbulent conditions where standard HAWTs lose efficiency due to sudden shifts in wind direction. VAWTs can provide electricity. Another important advantage is that the VAWTs may accept wind from any direction because they lack a yawing mechanism. Moreover, recent research has shown that placing the VAWTs in near clusters with distinct rotating orientations might improve their overall performance. Using a CFD solver fluently solving the Reynolds average Navier-strokes equation, a moving mesh technique was employed to investigate 2D unsteady flow around VAWT modeled with airfoils opening angles set to 60, 45, 30 and 15 degrees from main axis (1). For the purpose of evaluating energy performance and aerodynamic forces operating on a straight-bladed vertical-axis Darrieus wind turbine, the application of aerodynamic principles currently used in BE-M theory for rotor performance prediction to CFD has been presented (2). The search for workable and affordable small-scale wind energy harvesting methods for remote consumers or distributed power systems

is one area of focus (3). The entire system is first created using Solid Works, and then a 3-D printer is used to manufacture it as an experimental model out of PLA polymer material (4). In this study, we employ computational fluid dynamics (CFD) to examine a Savonius wind turbine's behavior in a flow field, as well as to assess the turbine's performance and wake geometry evolution. The wind turbine's design is qualified in part by the flow analysis (5). The current cascade model circumvents convergence issues that arise from the momentum theory when dealing with high tip speed ratios and turbines with high solidity (6). With an installed capacity of 6018 MW, India has the biggest annual percentage rise in wind energy installations and now holds the fourth position in the world (7). A lightweight, three-bladed practical prototype model of the VAWT is constructed using aluminum, with rotor diameter and height measurements of 0.36 and 0.40 meters, respectively (8). The third advantage is that the use of energy storage would aid in mitigating the fluctuations in power generation that intermittent and variable renewable resources provide into the system. The third advantage is especially significant as more renewable energy sources will eventually be included into the global electrical system (9). Three distinct Weibull distribution techniques were employed to determine the Weibull parameters, which were then confirmed by means of various commonly used statistical instruments (10). The purpose of this study is to examine how well wind turbines with vertical axes (VAWT) and those with horizontal axes (HAWT) function at varying wind speeds and behaviors. This study addresses the many kinds of VAWTs and HAWTs that are available, their benefits and drawbacks in urban and rural locations, and several ways to get around these restrictions (11). The ANSYS Fluent 15 program was used to conduct the computational analysis for a steady-state flow. An Artificial Neural Network (ANN) was used to quantitatively study and optimize many winglet designs with varying lengths and cant angles (12). Under computational approaches, the foundations of computational fluid dynamics (CFD) have been covered. A fluid structural interaction study or a finite element structural analysis can be used to examine the structural integrity of the turbine. Other useful methods, such as wind tunnel testing, have also been taken into consideration. Every method yields a distinct set of results, and the precision of the computational and numerical techniques may be assessed by contrasting their results with the results of experiments (13). The commercial ANSYS program was used to run the simulations. The acquired data demonstrated that the wind turbine power coefficient rises by approximately 5% when the turbine rotor deforms. Furthermore, it has been demonstrated that the centrifugal force cannot be disregarded as it significantly affects both turbine operation and rotor deformation (14). When the rotor rotates at a high angular velocity, the new strut type can maintain the rotor's deformation and equivalent stress within permissible material limits. When comparing UDWT to traditional two- and four-blade wind turbines, it has been demonstrated to enhance both structural and aerodynamic capabilities (15). Two approaches were used to examine the structural analysis of a VAWT blade structure under a critical load scenario: an analytical model and a finite element (FE) model. It was demonstrated that using a composite blade topology can withstand the flapwise stress that is created, and the material strains were kept within allowed bounds (16). In the current work, the effects of the two previously stated factors are investigated using high-fidelity CFD models that have been thoroughly validated using experimental data. For turbines with two, three, and four blades, the blade chord length may be changed to vary σ by 0.09 to 0.36 (17). The composite material's unidirectional strength is also evaluated in relation to the maximum design stress, and it is determined to be within reasonable bounds. Furthermore, the bamboo composite blades' stress and deflection are contrasted with those of traditional blade materials (18). In order to ascertain the highest values of deflection and bending stresses at the peak aerodynamic and centrifugal force values, the blade's design, including its

solidity, aspect ratio, pressure coefficient, and other factors, was investigated under extreme wind conditions. One kilowatt of electrical output was the target (19). Three different turbines are compared to each other in a case study. A analysis of the blade areas of several turbines is also provided. The vertical axis wind turbine appears to have several benefits over the horizontal axis wind turbine (20). The aerodynamic qualities are taken into consideration when designing a 3-blade, 4-blade, and 5-blade VAWT. Additionally, a computer research utilizing CFD is used to examine its performance, focusing on the impact of the blades' rotation and its interference with the other blades. A review of the literature is discussed, categorized according to computational investigations carried out with simulation tools and experimental analysis. The study's materials and techniques are covered, with thorough subsections outlining the CFD simulations and design process. Analysis is done to calculate the blade of the vertical-axis wind turbine, and the computational findings of the 3-, 4-, 5-, and 6-blade vertical-axis wind turbines are reviewed.

12

MATERIALS AND METHODOLOGY

Carbon fibers, sometimes referred to as graphite fibers, carbon fibers (CF), or graphite fibers, are fibers with a diameter of 0.00020–0.00039 inches (five to ten micrometers) that are mostly composed of carbon atoms. Carbon fibers have several advantages, including high stiffness, high tensile strength, and low weight to strength ratio, superior chemical resistance, high temperature tolerance, and little thermal expansion. Carbon fiber is widely employed in racing, aircraft, civil engineering, the military, and other competitive sports as a result of these qualities. They are nevertheless a little more expensive than other similar fibers like plastic, basalt, or glass fiber. Carbon atoms are linked in crystals that are approximately aligned parallel to the fiber's long axis to form a carbon fiber. The fiber has a high strength-to-volume ratio, or strength in relation to its size, as a result of its alignment. Thousands of bundles of carbon fibers make form a tow, which can be used independently or woven into fabric. After polyethylene and polypropylene, polyvinyl chloride is the synthetic plastic polymer that is produced on a global scale the third most frequently. Every year, about 40 million tons of PVC are produced. PVC is available in two primary forms: flexible and rigid (also referred to as RPVC). PVC is utilized in construction as a tough material for pipes and in profile applications like windows and doors. Moreover, it is utilized in the production of food-covering sheets, bottles, non-food packaging, and cards (like bank or membership cards). It can be softened and made more flexible by adding plasticizers, phthalates being the most common. This type finds usage in various applications where rubber is substituted, including flooring, signage, phonograph records, electrical wire insulation, plumbing, and inflatable items. It is utilized to make canvas when combined with cotton or linen. In VAWT, the airfoils are arranged so that they are symmetrical and angled so that the surfaces are aligned according to the design. This arrangement is equally effective in any wind. As the VAWT rotor rotates, the wing moves forward through the air in a circular motion. Relative to the cutting blade, the resulting air flow forms a different small positive effect on the cutting blade. This creates a general force that directs diagonally forward in a certain direction of action. This force can be projected some distance inward from the turbine shaft, resulting in a positive torque on the shaft. As the airfoil rotates around the rear of the unit, the angle of attack is reversed, but the resulting force is still biased towards the direction of rotation because the airfoils are symmetrical.. The rotor

rotates at a speed that is not related to the wind speed. Energy produced by torque and speed can be captured and converted into useful power. Lift and drag along the approaching relative airflow. When the rotor is stationary and the wind speed becomes high enough, the rotor must already be spinning to generate torque. So planning usually doesn't start by itself. In VAWT, because the wind turns the blades, the disk rotates with the speed of the wind and the shaft rotates with the same speed, so the power is transferred from the disk to an arrangement of gears that are welded to the bottom of the Shaft The generator receives power from the gearbox by connecting to the transmission and the output power is stored..

DESIGN OF THE VAWT WITH DIFFERENT NUMBER OF BLADES

The design of the blade was done using Solid Works software. Solid Works is computer-aided design software that now has features to add simulation features. Various 3D modeling operations such as extrusion, turning, peeling, patterning and also creating standard gears, bearings are easily performed.

1) 3 Blade, 4 blade and 5 blade

A Solid Works application is used to design the blade. First, the single blade is drawn and the thickness is noted. The circular pattern is then identified in order to obtain the required number of blades. An extruded single blade with a preset thickness is seen in the first drawing. The design is developed around a central shaft. The first step involves drawing and extruding a single blade to a predefined thickness. The design is developed around a central shaft. The fig. 1-3 shows that modal of 3, 4 and 5 blade.

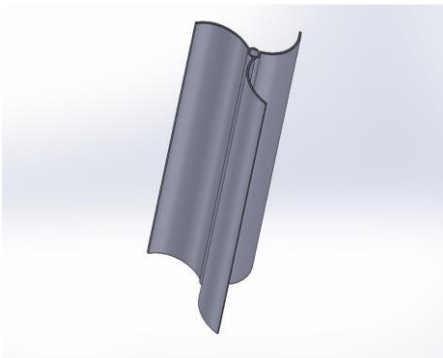


Fig 1. The 3 blade modal

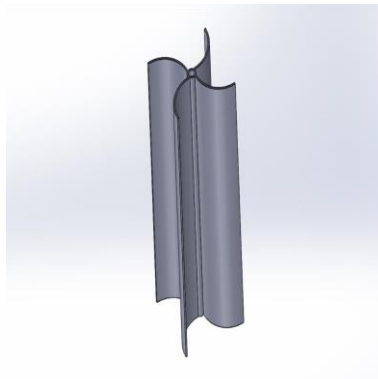


Fig 2. The 4 blade modal

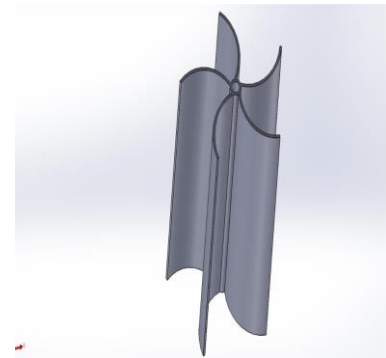


Fig 3. The 5 blade modal

RESULTS AND DISCUSSION

SIMULATION

ANSYS can import all kinds of CAD geometries (3D and 2D) from different CAD software and run simulations and can easily create. ANSYS is a built-in CAD development software and is like a Design Modeller. With multiple contact algorithms, time-dependent simulations and nonlinear material models, ANSYS is able to perform accurate and realistic advanced engineering

simulations. ANSYS can integrate different physics into one platform and perform analysis. As well as integrating thermal analysis with structural and fluid flow analysis with thermal and structural analysis. ANSYS has now developed ANSYS AIM as a product capable of performing multiple physics simulations. It is a single platform that can integrate all kinds of physics and run simulations.

MESHING

The process of dividing the geometry into finite elements is called meshing. The fig. 4 shows the meshing of the blade. Meshing process is done to divide the geometry into the elements each element is having the nodes. The nodes are the sections in which the partial differential equations corresponding to solve Navier Stokes equations in case of the CFD. The meshing produced here is the program-controlled meshing. The different elements available are the tetrahedral elements, hexahedral elements, square elements etc. The tetrahedral elements are formed in the outside enclosure. Square elements are formed in the blade section. The fig. 5 shows the turbine body.

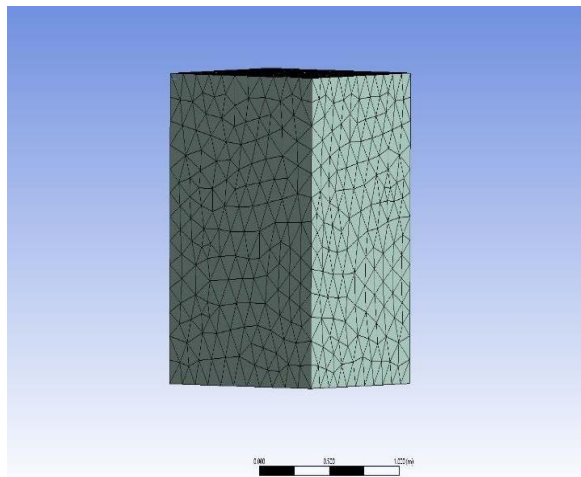


Fig 4. The mesh of the blade

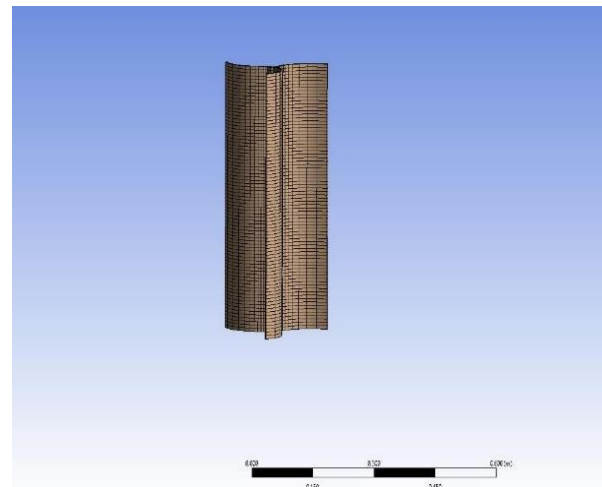


Fig 5. The turbine body

The boundary conditions enable us to seek the values of the constants in the equations. The boundaries assigned are: i) Inlet ii) Outlet iii) Wall iv) turbine body. Apply the viscous model: The viscous model chosen here is the K epsilon standard. Fig 6. Shows the iteration of the turbine. The model is sufficient in the wind turbine problems to accommodate the turbulence occurring here. The boundary condition that we provide in inlet section is motion of the wind. The wind is assigned a velocity of 8.33 m/s and an atmospheric pressure. The outlet that is specify is the pressure outlet that too is at atmospheric pressure. The method of the solution used here is the Simple method and the momentum and the turbulent kinetic energy as well as the turbulent dissipation rate. These solution methods have enabled the solution to converge at the very short period of time. The residual plot of transient CFD analysis is given above. The calculation is run at step size of .1 sec at 100 steps. The residual chart is given here.

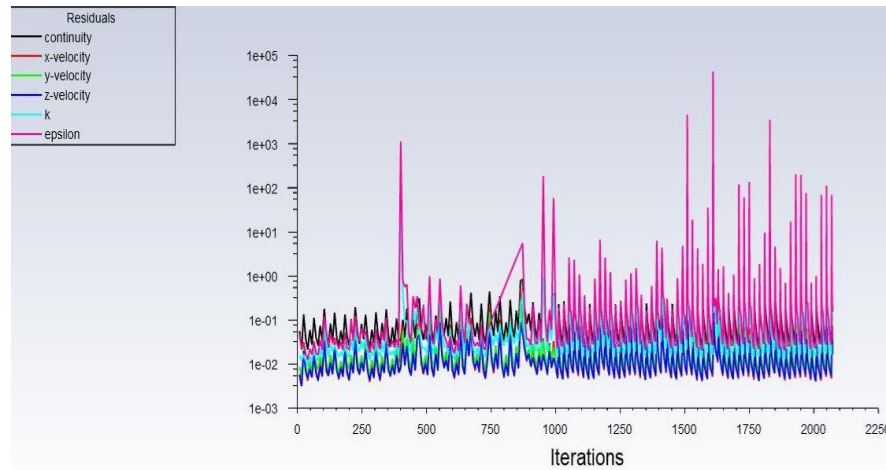


Fig 6. The iteration of the turbine

i) 3 Blade configuration using PVC material

The pressure contour and the velocity contour obtained during the steady state CFD analysis is plotted here. The different contour of the velocity distribution of air on the blades and the pressure imparted on the blades is shown here. The velocity contour shows the streamlines of the air over the air section. The pressure values are 253 Pa static pressure on the blade facing the wind direction. Fig 7 shows the pressure contour of the 3blade configuration.

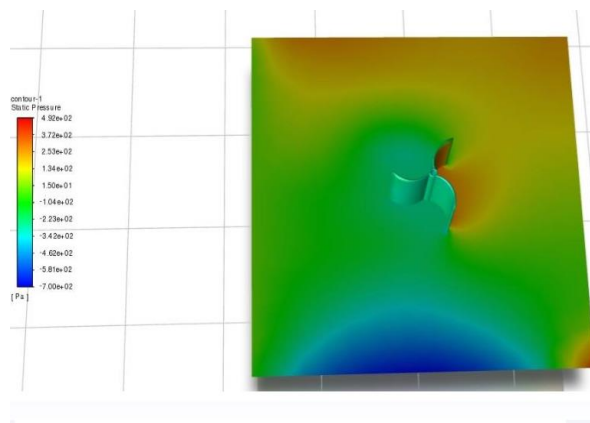


Fig 7. The pressure contour of the 3blade configuration

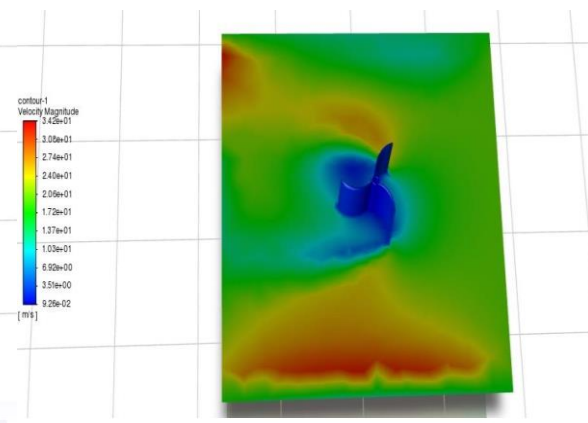


Fig 8. The velocity contour of the 3blade configuration

The result of the smooth CFD analysis is listed above. Fig 8 shows the velocity contour of the 3blade configuration. The pressure and velocity curves are given above. These contours describe the pressure change occurring. These values of the pressure exerted by the air particles on the

turbine blades are converted into rotational torque. A transient CFD analysis was performed to investigate the dynamic rotational state of the blades. Solution animations are obtained for dynamic analysis of air flow paths and turbine blades. The moment about the vertical axis is plotted here. Here also we can understand the period. The velocity of the air stream will create a moment of rotation about the Y axis which moves the blades. The moment is following a periodic change in the value which is depicted in the graph above.

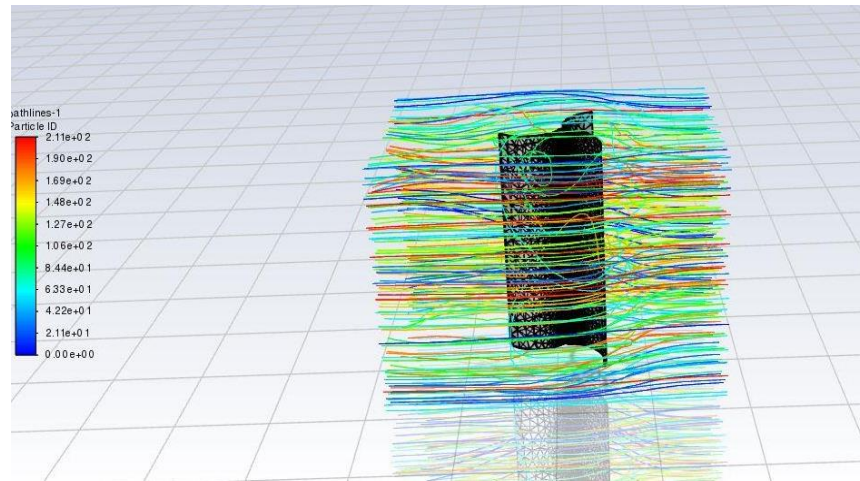


Fig 9. The path line representation of motion of the 3blade configuration

Fig 9. Shows the path line representation of motion of the 3blade configuration. The path line represents the motion of the fluid i.e., the air particles into the wind turbine body. The air particles will strike the wind turbine body hence the aerodynamic drag force will move the blades as result a rotating moment will be created. The path lines are assigned the field variable velocity and the particle velocity is plotted here. The velocity of the streamline of air flowing over the wind turbine is represented in the figure. These streamlines as they strike the wind turbine become denser near turbine blades. After the wind stream passes over the blades it expands. This creates a pressure difference before and after the turbine blades which is the sole cause of rotation of the blades of turbine.

ii) Result of 3 Blade configuration using Carbon fibre material

The results of both the material analysis is almost same because the two different material have almost same density. Figure 10 shows the velocity contour of the 3blade configuration. So the material change will produce only slight variation in the pressure contour and the velocity contour which is un noticeable. The material effects is very much negligible from the graph.

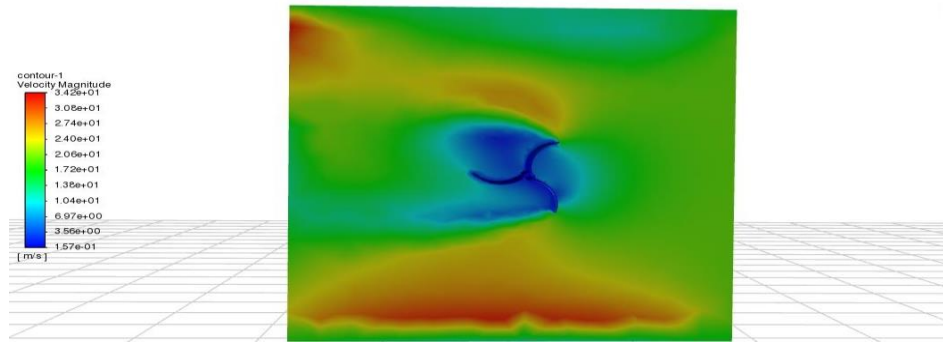


Figure 10: The velocity contour of the 3blade configuration

2. i) Result of 4 Blade configuration using – PVC as the material.

The material used here it's the PVC and the structural analysis is conducted on the model the obtained result is plotted.

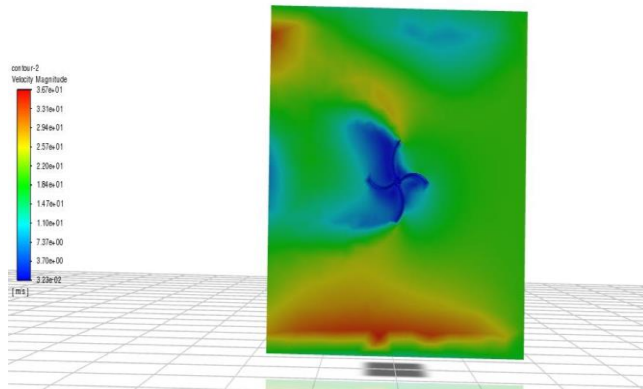


Figure 11: The velocity contour of the 4blade configuration with PVC

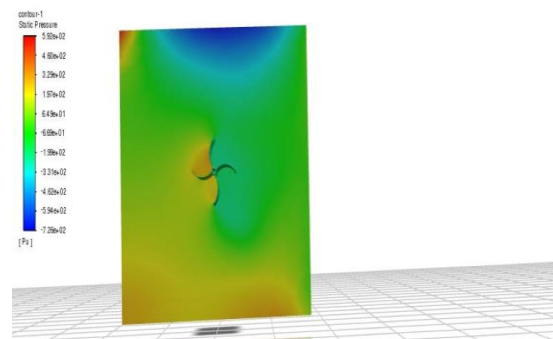


Figure 12: The pressure contour of the 4blade configuration with PVC

The velocity contour is the representation of the velocity of the fluid domain and the velocity across the walls of the turbine. Figure 11 shows the velocity contour of the 4blade configuration with PVC. The air jet is the different contour of the velocity distribution of air on the blades and the pressure imparted on the blades is shown here. The velocity contour shows the streamlines of the air over the air section. The pressure values are 253 Pa static pressure on the blade facing the wind direction. The result obtained from the steady CFD analysis is listed above. The pressure and the velocity contours are given above. Figure 12 shows the pressure contour of the 4blade configuration with PVC. These contours will be depicting the pressure change taking place. These pressure values exerted by the air particles on the blades of turbine is converted into rotational moment. To study the dynamic state of rotation of the blades the transient CFD analysis was performed. The calculation is run at step size of .1 sec at 100 steps. The solution animations are obtained for the path lines of air stream and the dynamic analysis of turbine blades.

\Results of transient CFD analysis of wind turbine with 4 blade configuration

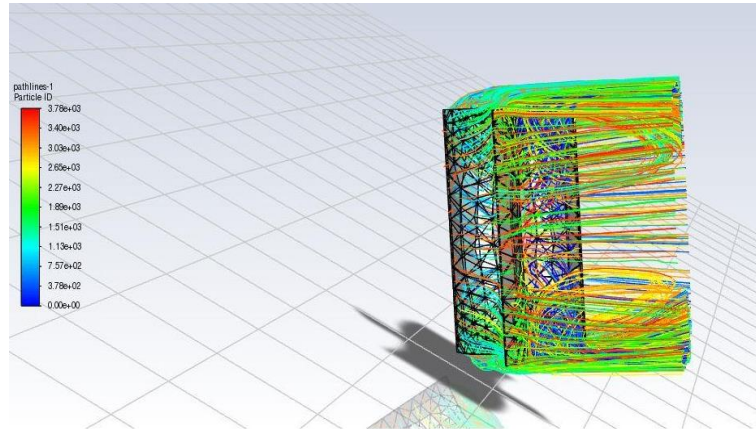


Fig: 13. The path line flow of the 4blade configuration

The air particles will strike the wind turbine body hence the aerodynamic drag force will move the blades as result a rotating moment will be created. Fig: 13 shows the path line flow of the 4blade configuration. The path lines are assigned the Field variable velocity and the particle velocity is plotted here. The moment versus flow time graph is represented over here.

ii) Result of 4 Blade configuration using – Carbon fibre as the material.

The material used here is the carbon fibre and the result of analysis produced similar contour for both the material

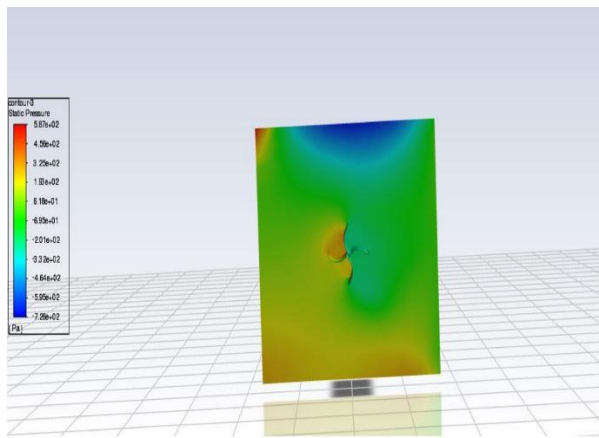


Fig: 14. The pressure distribution of the 4blade configuration

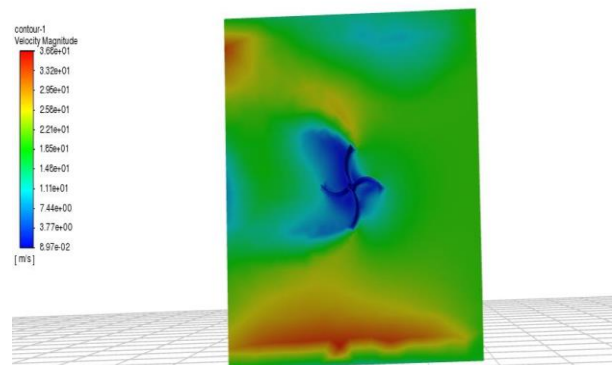


Fig: 15. The velocity distribution of the 4blade configuration

The velocity contour is the representation of the velocity of the fluid domain and the velocity across the walls of the turbine. The different contour of the velocity distribution of air on the blades and the pressure imparted on the blades is shown here. Fig: 14 and Fig 15 shows the pressure distribution of the 4blade configuration and the velocity distribution of the 4blade configuration. The velocity contour shows the streamlines of the air over the air section. The pressure values are 253 Pa static pressure on the blade facing the wind direction. The result obtained from the steady CFD analysis is listed above. The pressure and the velocity contours are given above. These contours will be depicting the pressure change taking place. These pressure values exerted by the air particles on the blades of turbine is converted into rotational moment. To study the dynamic state of rotation of the blades the transient CFD analysis was performed.

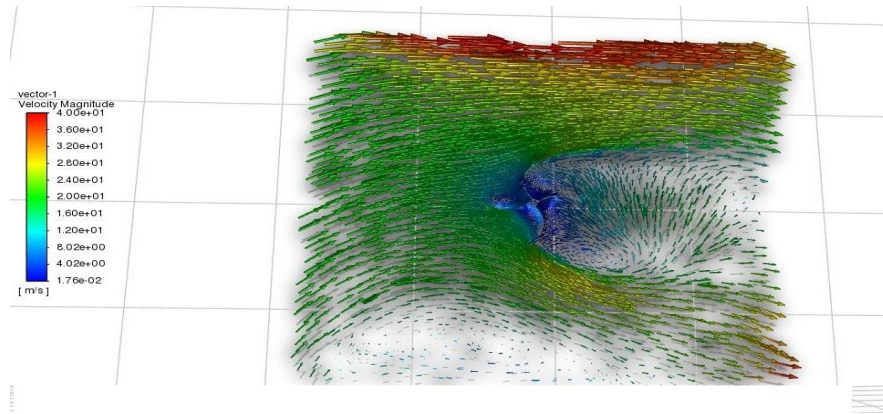


Fig: 16. The velocity vector of the 4blade configuration

The carbon fibre and the PVC produced similar results on the dynamic analysis of the turbine blades. Fig: 16 shows the velocity vector of the 4blade configuration. Hence it is clear that the both will give the similar results in torque produced. The moment versus flow time graph is represented over here. The moment value is showing both the maximum as well as the minimum values as the periodic rotation of the blades.

3. Result of 5 Blade configuration using – PVC as the material.

The material used is here the PVC and the rest conditions are kept constant and the result is plotted.

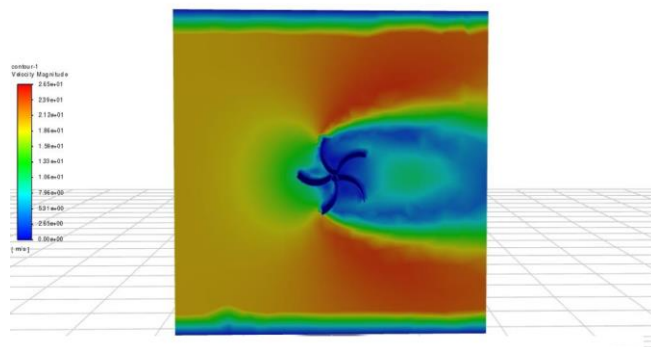


Fig: 17. The velocity distribution of the 5blade configuration

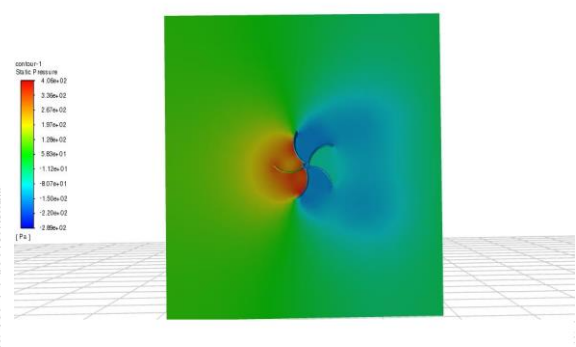


Fig: 18. The pressure distribution of the 5blade configuration

The result obtained from the steady CFD analysis is listed above. Fig: 17 and Fig 18 shows the velocity distribution of the 5blade configuration and the pressure distribution of the 5blade configuration. The pressure and the velocity contours are given above. These contours will be depicting the pressure change taking place. These pressure values exerted by the air particles on the blades of turbine is converted into rotational moment. To study the dynamic state of rotation of the blades the transient CFD analysis was performed. The calculation is run at step size of 0.1 sec at 100 steps. The solution animations are obtained for the path lines of air stream and the dynamic analysis of turbine blades. The maximum and the minimum value of the moment is represented in the graph. The periodic change in the moment is due to the periodic movement or rotation of the blades of the turbine. Maximum value is 0.9 N/m. The moment about the vertical axis is plotted here. Here also we can understand the period.

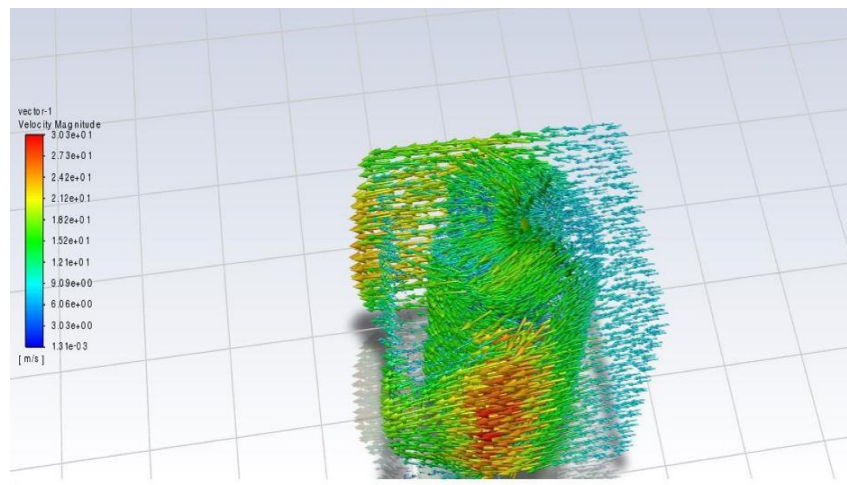


Fig: 19. The Velocity vectors of air passing over wind turbine

This figure represents the path lines of air particles tracing over the wind turbine blades. Fig: 19 shows the Velocity vectors of air passing over wind turbine. The path lines represent the motion of the fluid i.e. the air particles into the wind turbine body. The air particles will strike the wind turbine body hence the aerodynamic drag force will move the blades as result a rotating moment will be created.

ii) Result of 5 Blade configuration using – Carbon fiber as the material.

The contour result of the CFD analysis of the wind turbine using the carbon fiber as the material. Fig: 20 shows the Wall shear stress acting in the material. The results can be used to infer that the material change doesn't produce the same result as produced in case of the PVC material. Figure shows that the moment graph is similar to that of the PVC material. Hence it can be proved that the results are similar in nature.

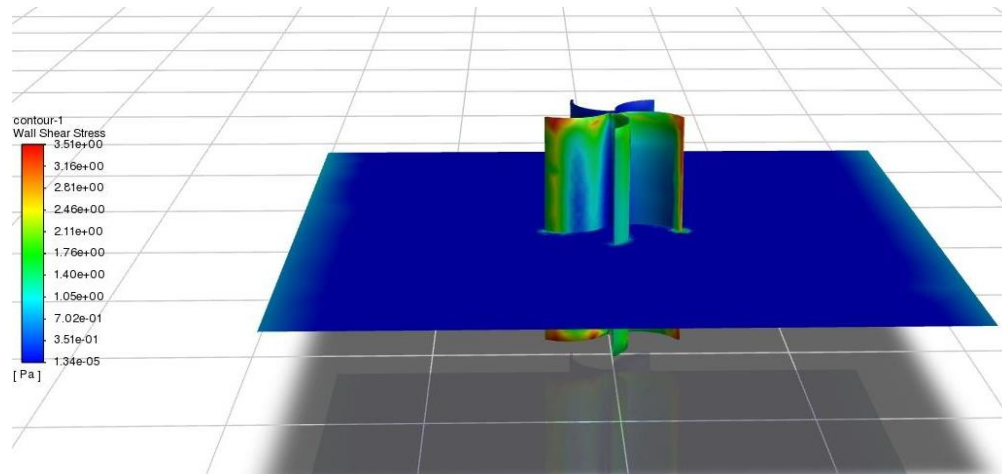


Fig: 20. The Wall shear stress acting in the material

CONCLUSION

The wind turbine is the subject of both the structural and CFD analyses. We can identify the streamline motion of the air above the wind turbine thanks to the interpretation of the analysis's results. Studying the air stream's aerodynamic impact on the turbine blades is crucial. The streamlining analysis demonstrates that air will produce a denser area over the turbine blades, and that air will then impose drag force after passing over, allowing the turbine blades to move ahead. The streamlining analysis demonstrates that air will produce a denser area over the turbine blades, and that air will then impose drag force after passing over, allowing the turbine blades to move ahead. Because the three-blade arrangement has a greater drag force, it produces more energy. The drag force generated is greater than 20 N, which is adequate to drive the blade and generate energy. The aerodynamic parameters obtained by each blade design were identical, with the exception of a minor variance in the instant reaction value. As the number of blades rises, the moment value increases marginally. The difference results from more surface area being exposed to the high-velocity air's pressure. PVC and carbon fiber, the two distinct materials used here, generated moment and drag force values that were comparable. These patterns are clear justification that the both materials produced similar motion of the blades. So further to study the change of the material induced characteristic we proceeded to the structural analysis of the turbine blades. The structural analysis proved that the stress distribution across the blades has a noticeable difference. The maximum value of the stress is found in the material carbon fibre. So more energy will be produce by this material rather than the PVC.

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