DESIGN AND ANALYSIS OF VERTICAL AXIS WIND TURBINE ON SMALL SCALE ENERGY PRODUCTION

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ABSTRACT

This research work is conducted for computing the performance of vertical axis wind turbine. Computational Fluid Dynamics (CFD) software is used to analyze the mechanical performance of VAWT. The two bladed and three bladed VAWT performance is calculated by simulating each VAWT by using CFD software. Vertical Axis Wind Turbines (VAWTs), can be installed in the locations where the wind speed is low. The aim is to develop a VAWT with improved turbine performance to harvest electrical energy more economically and sustainably. The spiral design is capable to sweep wind efficiently and it has less negative effect of torque on reversing blade which is the main advantage. The CFD analysis is used to understand the performance of two bladed and three bladed VAWT before fabrication in result efficiency is increased. The efficiency of 24.63% and 24.93% obtained for two bladed and three bladed VAWT.

Keywords

Computational fluid dynamics (CFD)
Vertical axis wind turbine (VAWT)
Coefficient of power (C_p)

1 Introduction

The wind energy is a sustainable renewable energy source which is an alternate to non-renewable energy sources and depleting day by day which is a concern of increasing pollution and global warming. Wind energy is replacing the fossil fuels, as the price and supply chain is not stable. Therefore wind energy is a better solution for energy security at global level [1]. It is forecasted that renewable sources might contribute 20% to 50% energy consumption in the upcoming part of the 21st century [2]. Global Wind Energy Council (GWEC) predicted that the installed capacity of wind is contributed to 591 GW by the end of year 2019 [3]. The wind turbines used for harnessing electrical energy are of two types Horizontal Axis Wind Turbine (HAWT) and Vertical Axis Wind Turbine (VAWT). The main difference is the axis of rotation of the wind turbine rotors and generator in which all components are horizontally arranged in HAWT while vertically arranged in VAWT [4].

The main advantage of VAWTs are not depending on the wind directions therefore no yaw mechanism is required for facing the wind direction. VAWTs are also easier to design and built, compared with HAWTs [19]. HAWTs need yaw mechanism, designs are continuously getting bigger to produce more power.

Wind deflecting plates integrated in front of the rotor and compared the lengths of the curtain blades with the angles of the blades and adjusted to experiment the effective flow field. The parameters such as power coefficient of wind turbine calculated by changing length and angle of attack of the blade used for concentrating wind to strike the wind turbine rotor effectively [5]. A vertical axis wind turbine which is consisting three half-cylinder blades, end plates by coupling solid shaft and experimented turbine in a wind tunnel. Dynamic performance influenced near the concave side of the blades. But not gained desired static and dynamic performances [6]. A residential Vertical Axis Wind Turbine presented, equipped and could be used in remote area. Turbine model was simulated and parameters named as Power Coefficient and Tip Speed Ratio obtained in Matlab software and calculated efficiency of the prototype [7]. The performance of turbine was analyzed at wind speed ranges between 1 m/s to 6 m/s and obtained power coefficient with respect to tip speed ratios in wind tunnel by utilizing X-Flow Computational Fluid Dynamics (CFD) software [8, 20]. Comparison of the generated voltage and the turbine speed evaluated with the blade angle at different wind speed [9]. In one of the research work by changing angle of attack can lead to a self-starting at low wind speeds. Also the angle of attack has impact on the lift and torque [10]. The Dual-VAWT having two axes, increased the swept area and extend the region of maximum power generation of a typical VAWT [11]. Deflector installed around wind turbine which redirected the fluid flow from the returning turbine blade and in result reduced the negative torque acting on the wind turbine system [12]. The parameters such as turbine solidity, blade number, blade aspect ratio was determined for a Vertical axis wind turbine [13, 21]. The systematic analysis showed that the effectiveness of VAWT system and the potential to extract threefold power over the operating wind speed ranges [14, 22]. In a research work study it was analyzed that the mechanical performance is dependent of types/patterns, numbers of blades, and height-to-radius ratio [15]. Numerical method was used to investigate the performance of the high aspect ratio vertical axis wind turbine [16, 23].

The rpm of vertical axis wind turbine are taken from the experimental work carried out at different wind speeds 3 m/s to 9 m/s by manganhar et.al. In their work the power coefficient of rotor obtained was 0.125 for without rotor house wind turbine [17, 24].

In this research Vertical Axis Wind Turbine (VAWT) having aerodynamically varied geometry result in increased efficiency. Much of the wind strikes the VAWT and sweeps very easily in result increases the efficiency.

2 Methodology

In this research CAD model of vertical axis wind turbine is designed. Numerical parameters i.e. power coefficient, torque, and force is calculated by using ANSYS CFD (computational fluid dynamics) software.

2.1 CAD Model

The CAD model of the design is developed in Solid works software. The design parameters of VAWT are given in the table below.

Parameters of VAWT	Diameter (D)	0.25 m
	Height (H)	0.25 m
	Area of the turbine blades = D×H	0.25 x 0.25 = 0.0625 m^2

Table 1 Design Parameters VAWT

The two bladed and three bladed VAWT designed in solid works software is shown in figure 1 and 2 below. The blades of two bladed VAWT are equally spaced at an angle of 180^0 and each blade is twisted at 120^0. Similarly the blades of three bladed VAWT are equally spaced at an angle of 120^0 and each blade is twisted at 120^0.

Figure 2.1 Two bladed Spiral VAWT

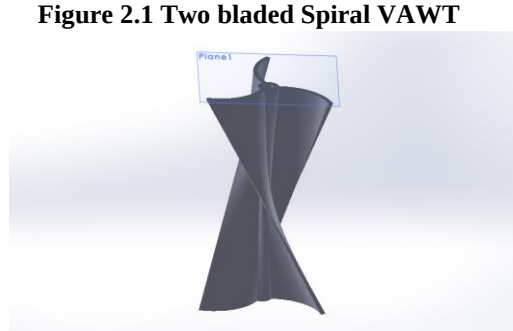

Figure 2.2 Three bladed Spiral VAWT

2.2 CFD Analysis

CFD analysis of Vertical Axis Wind Turbine (VAWT) is investigated in this work. CFD analysis provide a wide spectrum of fluid flow surrounding the wind turbine and also provide the comprehensive performance of VAWT.

2.3 Fluid Flow setup

The flow field characteristics such as Velocity Field Analysis and Pressure Field Analysis across the wind turbine is investigated in order to determine the performance of VAWT by determining the parameters i.e. force, torque and power coefficient of VAWT at different wind speeds 3 m/s to 9 m/s. The parameters are numerically computed in CFD fluent 15.0 separately for two bladed and three bladed VAWT.

2.4 Aerodynamics of the VAWT

The tip speed ratio (TSR) is defined as the ratio of velocity of wind turbine blade to the wind velocity. It is a non-dimensional number and is denoted by λ;

$$\lambda = \omega * R / V \qquad (1)$$

Where ω is the angular velocity, V is the wind velocity, R is the radius of turbine rotor.

The important parameters of wind turbine performance, namely the coefficient of torque (C_T) and the coefficient of power (C_P), being defined as follows [25];

$$C_T = T/0.5.\rho.A.R.V^2 \qquad (2)$$

$$C_P = P_m/P_w = P/0.5.\rho.A.V^3$$

$$= T.\ \omega.R/0.5.\rho.A.R.V^3 = \lambda.C_T \qquad (3)$$

$$P = 0.5.\rho.A.V^3.\ C_P \qquad (4)$$

2.5 Discretization and boundary condition

During the simulation, two domains had been modeled: a cube for the rotor domain and a cylinder was modeled in ANSYS for the VAWT rotor as shown in Fig. 2.3. The boundary conditions also applied. At inlet wind velocity is considered whereas at outlet pressure is considered zero. The size of stator domain was selected 20D (width) in y direction, 20D (height) in z-direction and 50D (length) in x direction .The VAWT rotor domain was taken as rotational diameter 3D and 0.2 m distance taken for the top and bottom. The rotor domain of turbine was located at a distance of 20D from the inlet and 30D from the outlet.

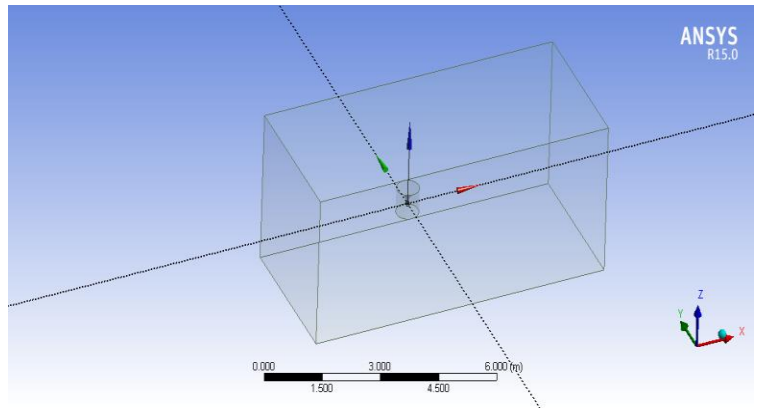

Figure 2.3 Domain of VAWT

The following parameters employed taken from the experimental work of manganhar et.al for turbine without rotor house [17].

Wind Speed (m/s)	RPM of VAWT
3	87
5	200
7	305
9	420

Table 2 Parameters of VAWT

After defining the rotor domain and boundary conditions the meshing of VAWT is generated for VAWT as shown in figure below.

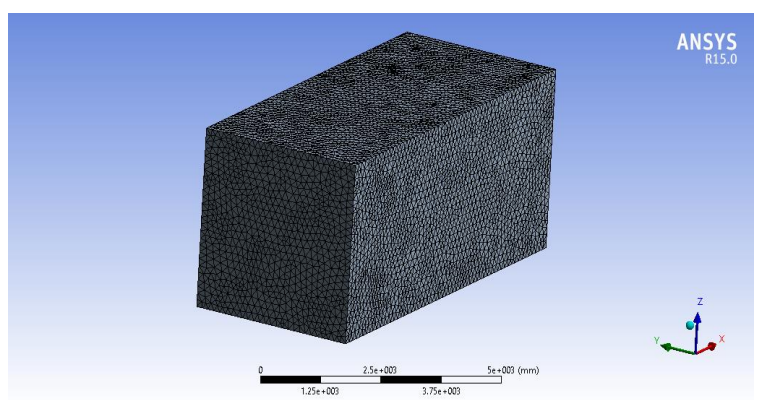

Figure 2.4 Meshing of VAWT

2.6 Solution setting

The pressure velocity coupling solution used the SIMPLE method to solve the Navier-Stokes equation. In spatial discretization least square cell based, second order pressure and second order upwind selected for momentum, turbulence kinetic energy and turbulent dissipation rate. The fluid named air was used having density 1.225 (kg/m^3) and viscosity 1.7894 10^5 (kg/m,sec). The force and torque were simulated and observed for two bladed and three bladed VAWT using ANSYS Fluent. In calculation setting the time step size is taken as 0.001s, number of time steps 20 and maximum iterations for each time step selected is 5.

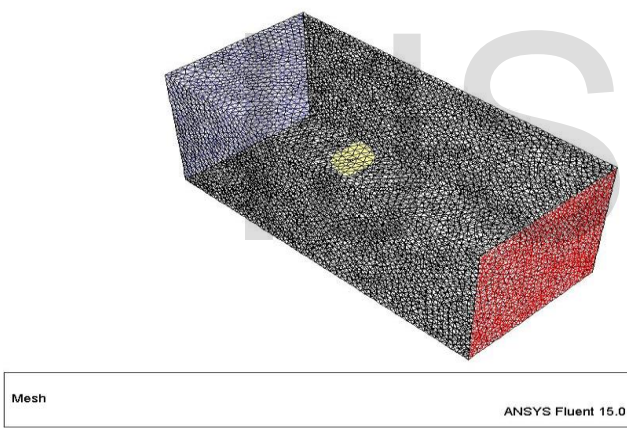

Figure 2.5 Solution setup of VAWT

3 Results and Discussion

3.1 Numerical (CFD) analysis of Vertical Axis Wind Turbine (VAWT)

Numerical analysis of two bladed and three bladed vertical axis wind turbine is analyzed in ANSYS 15.0 software by using the transient CFD analysis. The results are discussed below;

3.2 Analysis on force of VAWT

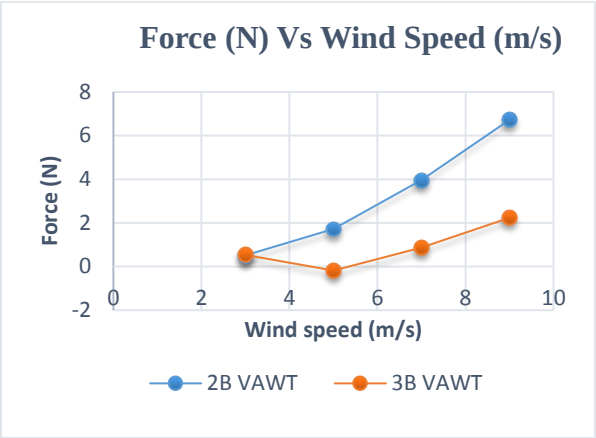

Figure 3.1 Force on VAWT Vs Wind Speed

The figure 3.1 shows that the force acting on the Spiral VAWT at different wind speed. The drag force of VAWT is increasing with increase in wind speed. The Transient CFD analysis of wind turbine carried out from wind speeds 3 m/s to 9 m/s. The force acting on two bladed VAWT is more compared to three bladed VAWT.

3.3 Analysis on torque of VAWT

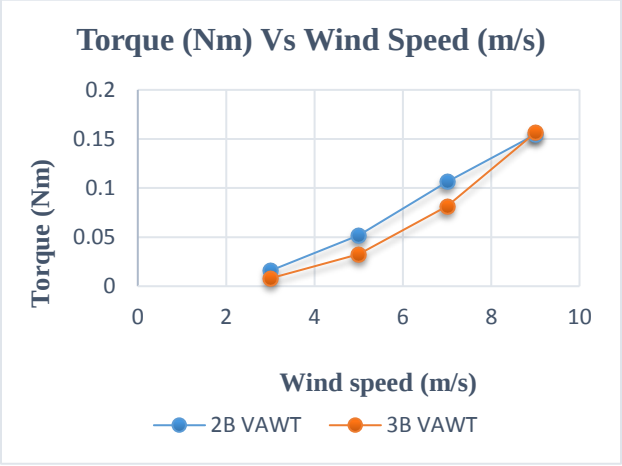

Figure 3.2 Torque Vs Wind Speed

The figure 3.2 shows the torque of the Spiral VAWT at different wind speeds. The torque of VAWT is increasing by increase in wind speed. The torque of two bladed VAWT is initially more compared to three

bladed VAWT from 3m/s to 7m/s and then torque of three bladed VAWT is more compared to two bladed VAWT.

3.4 Analysis on power coefficient (Cp) of VAWT

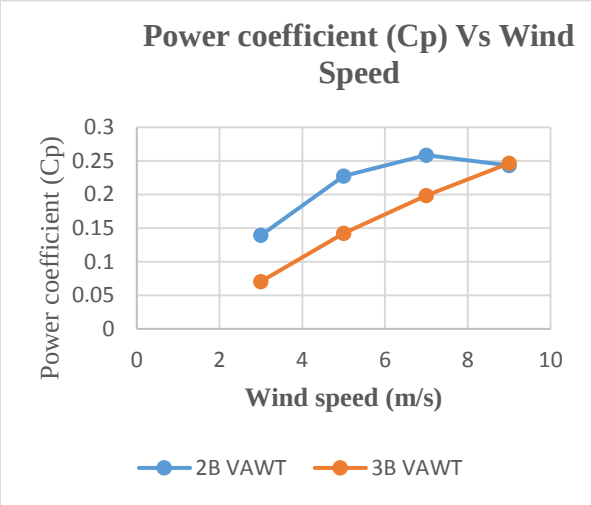

Figure 3.3 Power coefficient Vs Wind Speed

The figure 3.3 shows that the coefficient of power (C_P) of the Spiral VAWT at different wind speed. The power coefficient of two bladed VAWT is increasing with increase in wind speed initially up to 7 m/s then power coefficient is decreasing with further increase in wind speed. This decrease in coefficient of power is due to the negative effective of the torque on reversing blade. Whereas the power coefficient of three bladed VAWT is increasing with increase in wind speed. The Transient CFD analysis of wind turbine carried out at wind speeds 3 m/s to 9 m/s.

3.5 Analysis on power coefficient (Cp) of VAWT

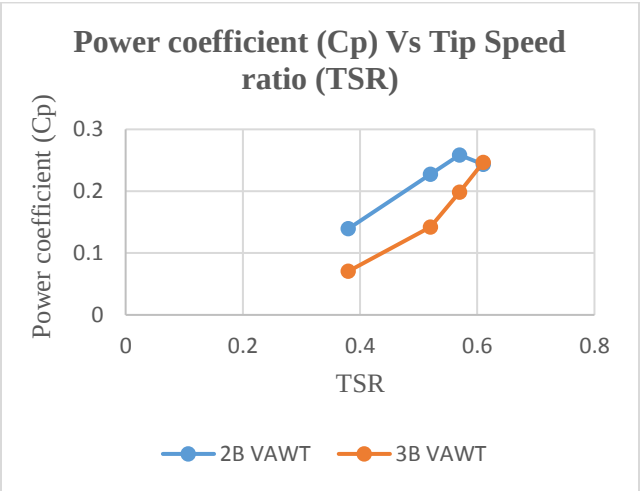

Figure 3.4 Power coefficient Vs Tip Speed ratio

The figure 3.4 shows that the coefficient of power (C_P) of the Spiral VAWT at different tip speed ratio. The coefficient of power (C_P) of VAWT is increasing with increase in tip speed ratio therefore the power coefficient and tip speed ratio has the direct relation with each other. The coefficient of power (C_P) of vertical axis wind turbine VAWT having 2 blades is more compared to three bladed VAWT from 3 to 7 m/s. The power coefficient of three bladed VAWT is continuously increasing from 3 m/s to 9 m/s and power coefficient is exceeding at 9m/s compared to two bladed VAWT. The Transient CFD analysis of wind turbine carried out at wind speeds 3 m/s to 9 m/s.

Wind Velocity magnitude during the flow in the rotor domain from inlet to outlet at different wind speed ranging from 3m/s to 9m/s during the CFD analysis is shown in following figure:

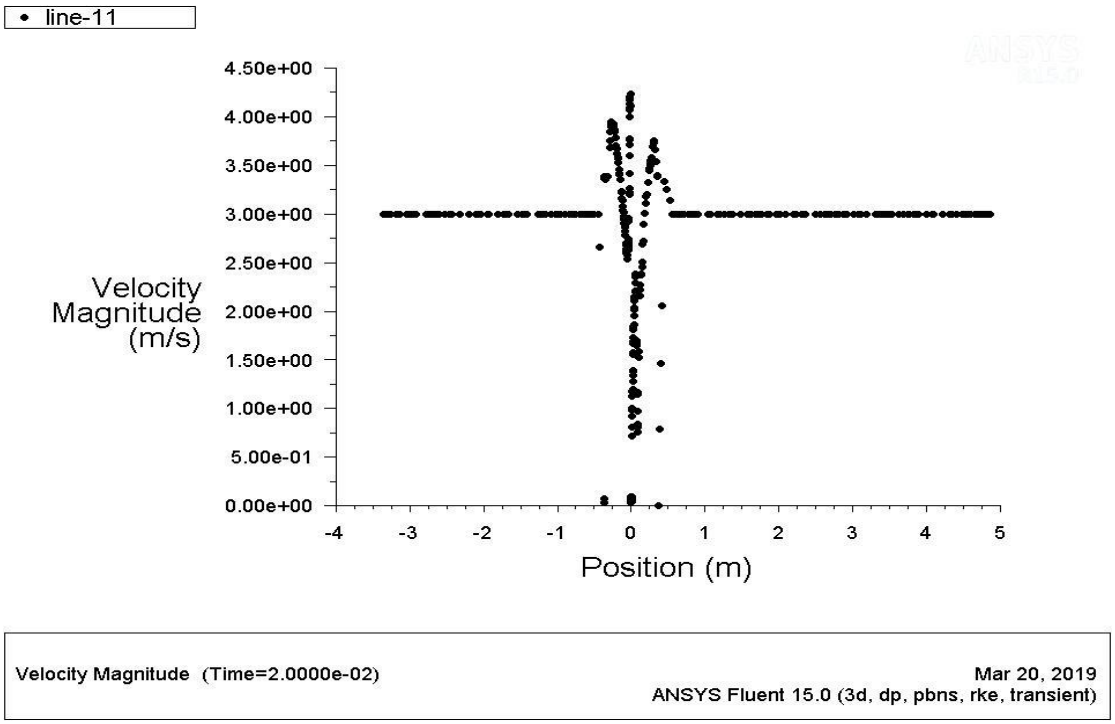

Figure 3.5 Wind velocity magnitude at 3m/s

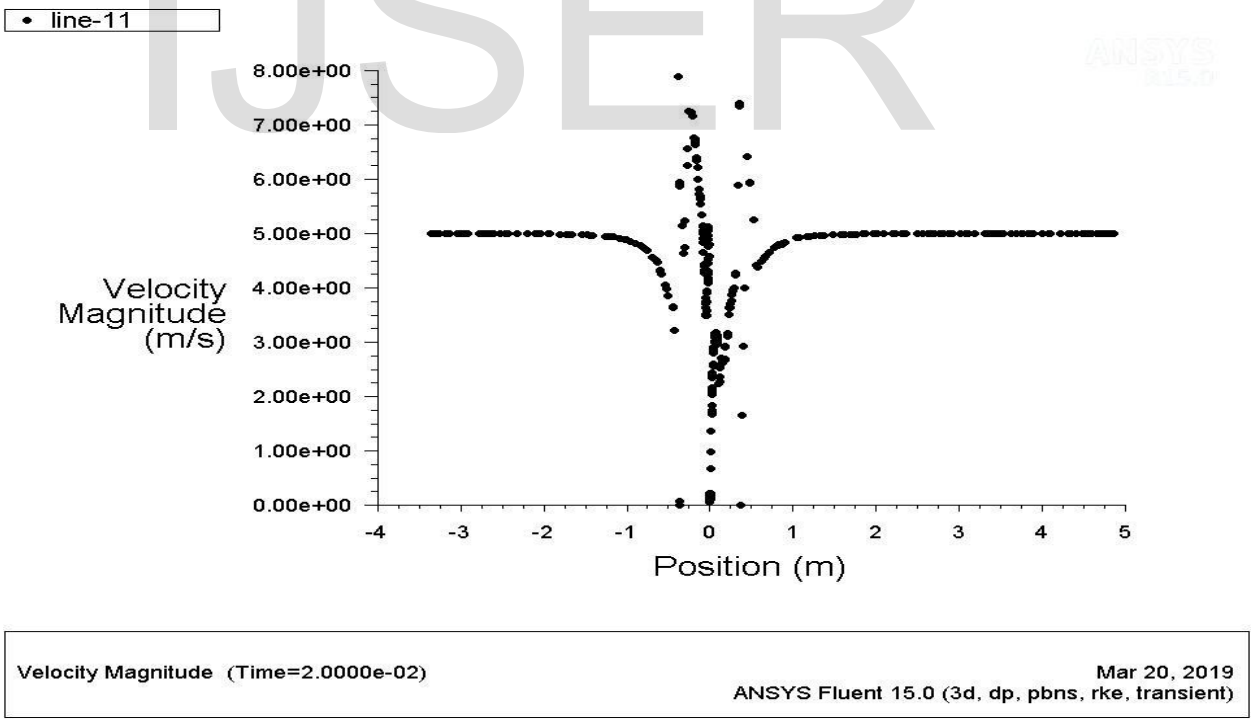

Figure 3.6 Wind velocity magnitude at 5m/s

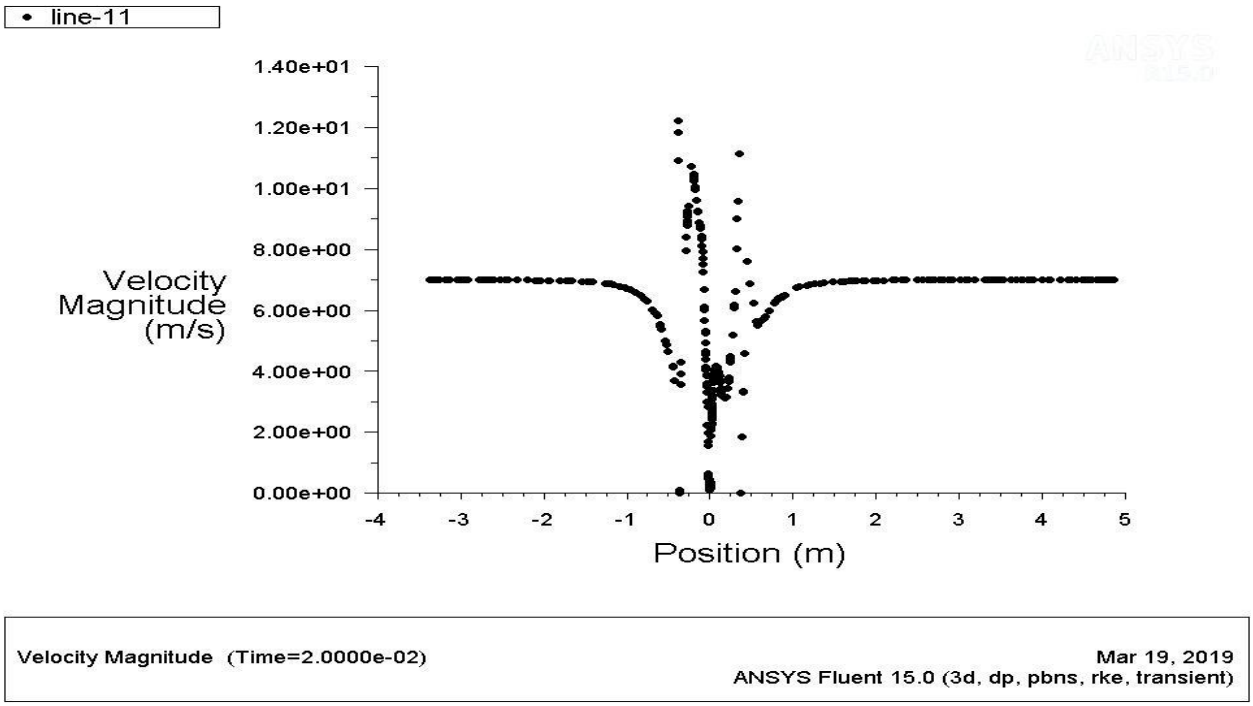

Figure 3.7 Wind velocity magnitude at 7m/s

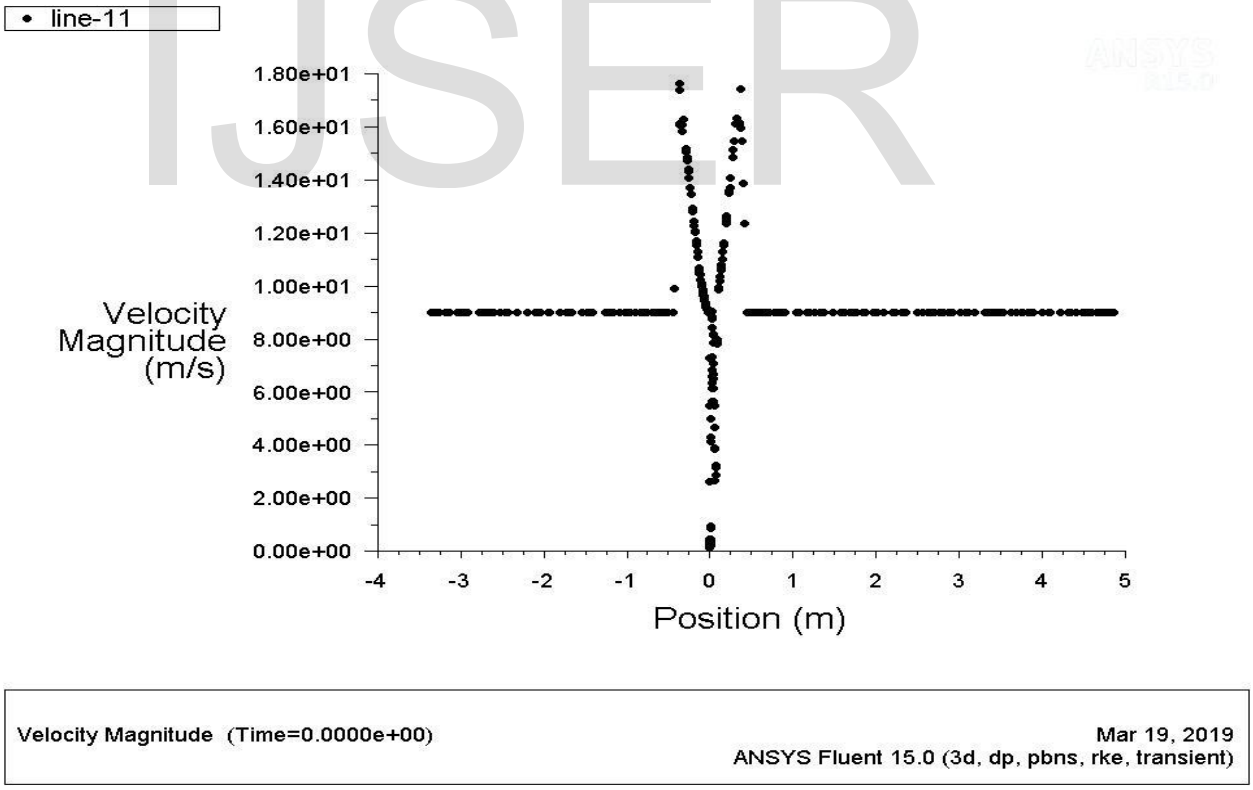

Figure 3.8 Wind velocity magnitude at 9m/s

From figure 3.5 to 3.8 the wind velocity behavior is shown where it is observed that wind velocity before and after striking the wind turbine is same. Wind velocity is varying in the rotor zone and after striking the wind turbine the wind velocity is stabilizing and becomes uniform.

4 Conclusion

CFD based simulation is an important development to calculate the performance of wind turbine. The force, torque and power coefficient of the Vertical Axis Wind Turbine (VAWT) is more than the conventional VAWT for the same wind speed. This is due to the design changed for VAWT with this negative effect of torque is reduced which overcome the friction. The wind turbine rotor of spiral shape is designed in which each blade is twisted to angle of 120 degree. Also this spiral design is capable for self-starting. VAWT does not require any significant land for installation, as it can be easily installed in rooftop, tower, and buildings. Therefore the output potential of wind farms is significantly increased. The maximum efficiency named as power coefficient of 25.85% obtained for two bladed VAWT at 7m/s and 24.93% obtained for three bladed VAWT at 9m/s during the CFD analysis at wind speed from 3 m/s to 9m/s. Therefore it is concluded that with further increase in wind speed from 7m/s the three bladed VAWT is efficient than two bladed VAWT.

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