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To cite this article: A. Abraham Eben Andrews *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **574** 012007

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# Experimental and Numerical Study on Modified Vertical Axis Wind Turbine

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**Abstract:** Wind energy is very important in the development of sustainable energy with the growing focus on renewable energy; interest in design of wind turbines has also been expanding. In today's market, the horizontal axis turbine is the most common type in use; Experimental data of this research is to compare the CFD Analysis with the Experimental Data of hybrid Modified vertical axis wind turbine. The graphical data based on the parameters such as Velocity, Power Coefficient, Tip Speed Ratio Vs Power Coefficient and Wind Velocity Vs Power Coefficient, which are discussed in this research. The Savonius turbine (Lift Turbine) was attach with the Gorlov turbine (Drag driven turbine) for the self-starting of the hybrid-modified turbine. Here the design, construction and testing of vertical axis wind turbine with three blades, starting solely from low energy of the wind. The velocities such as 5, 7, 9 and 11 m/s are tested in CFD Analysis for checking from which maximum power can be extracted so it can be used in desert area.

## 1. Introduction

In present days renewable energy is motivated to use due to the increase in environmental problems mainly focusing on the global warming, windenergy plays a vital role in the renewable energy In India renewable fuel requires many technological improvements [1]. Horizontal Axis Wind Turbines (HAWT) and Vertical Axis Wind Turbines (VAWT) are the classifications of wind turbine. In many countries for medium-to-large scale Energy generations Horizontal axis wind Turbine is used and it isnot recognized as a viable option to harness the energy of the wind in urban areas, where the wind is less intense, much more chaotic and turbulent. Vertical axis Wind Turbine are suggested for large scale deployment as a better choice for cities areas because of their good performance even in weak and unstable wind[2]. To generate the Lift aerodynamic bodies like airfoil required in darries type wind turbine. So darries is costlier than Savonius type wind turbines. Savonius Vertical axis wind turbine was named after its inventor Sigurd. J. Savonius [3]. The performance analysis of Savonius turbine is done by analysing the importance of its geometrical parameters like overlap ratio, aspect ratio, gap ratio and shape parameters [4].

Vertical axis wind turbineas shown in Figs. 1 combines the working principle of Drag and Lift type vertical axis wind turbine the solid model of this turbine is created in ANSYS Fluent workbench [11]and CFD analysis is carried out the suitable design is fabricated and tested in

wind tunnel. The raw data measured during the open environment test on this wind turbine are wind speed (V), rotational speed of the rotor shaft and load applied on the dynamometer.

These data are processed and presented as per the wind turbine research community approach also provides the aerodynamics performance of the Wind Turbine in terms of dimensionless parameter as coefficient of power ( $C_p$ ) and coefficient of torque (CT). Further to disclose the influence of tip speed ratio (TSR) on aerodynamic performance, the variations of TSR with  $C_p$  and CT at different wind velocities [9]. Rotor showed its peak performance at an overlap of 0.16. Sukanta Roy and Ujjwal Saha [4] tested modified Bach type vertical axis wind turbine design and the results were compared with normal types. Kamojiet al [5] studied the torque formation in negative way in simple Savonius rotors and found that simple 90 degree twist can overcome this with a helical Savonius rotors. Damak [6] tested helical Savonius rotors with 180° twist in a wind tunnel to determine aspect ratio. Sukanta Roy and Ujjwal Saha [7] tested the modified Savonius in a wind tunnel and the new design shows good performance. Khandakar Niaz Morshed et al. [8] analysed three bladed Savonius rotor by numerically and experimentally to predict overlap ratio is optimum. The authors found that overlap ratio of 0.2 suits the hydroturbine. Muscoloa and Rezia Molfinob [10] developed a new blade design named Broznius rotors.

## 2. Design of Wind Turbine

### 2.1 Selection of Wind Turbine

As there are many types of vertical axis turbines with various efficiencies, life time and cost. Gorlov turbine has been selected from the following table based on the following parameters [12].

Table 1 Performance Comparison of Vertical Turbines

	H ROTOR	TURBY	GORLOV
Type (VAWT)	Darrieus	Darrieus	Darrieus
Swept Area (m <sup>2</sup> )	7.29	N/A	N/A
Cut-in wind speed (m/s)	3.9	4	5
Cut-out wind speed (m/s)	N/A	14	26
Rotor Diameter (m)	2.7	1.9	3.1
Weight (kg)	135	136	N/A
Expected Lifetime (years)	20	20	25
Annual energy production (kWh/yr)	2000-4000	N/A	4197 @ 5 m/s, 7000 @ 7 m/s
Rated power (kW)	1.7	2.5	6.5
Total height (m)	7.9/12.5/18.6	6	13

### 2.2 Selection of Blade Angle and No of Blades

Number of blade selected is 3 and at an angle taken is 58.37 degree [13]. The table show the values of solidity ratio of both the blades in their same angle (58.37 degree) approximately same.

Table 2 Various Parameters of Turbine

$\Phi$ (degree)	N	H(m)	D(m)	C(m)	$\Sigma$
43.68	3	0.75	0.75	0.15	0.191
51.85	3	0.8	0.6	0.15	0.239
58.37	3	0.85	0.5	0.15	0.286
47.5	3	0.8	0.7	0.15	0.205
51.85	4	0.75	0.75	0.12	0.204
59.5	4	0.8	0.6	0.12	0.255
65.2	4	0.85	0.5	0.12	0.306
55.5	4	0.8	0.7	0.12	0.218

### 2.3 Wind Turbine Design Parameters

The wind turbine parameters considered in the design process are:

For Gorlov Turbine:

Height of Turbine,  $H = 0.8\text{m}$ , Diameter of Turbine,  $D = 0.5\text{m}$

No. of Blades,  $N = 3$

Chord Length,  $C = 0.15\text{m}$

Density of Air,  $\rho = 1.225 \text{ kg/m}^3$

Swept Area,  $A = D \times H = 0.8 \times 0.5 = 0.4\text{m}^2$

Solidity,  $\sigma = (NC) \div (2\pi r) = (3 \times 0.15) \div (2 \times 3.14 \times 0.25) = 0.2864$

Aspect Ratio =  $H \div D = 0.5 \div 0.8 = 1.666$

For Savonius Turbine:

Height of Turbine,  $H = 0.25\text{m}$ , Diameter of Turbine,  $D = 0.5\text{m}$

Diameter of Blade,  $d = 0.3\text{m}$

Eccentricity,  $e = 0.1\text{m}$

Aspect Ratio =  $H \div D = 0.5$

### 3. Construction of Wind Turbine

A shaft of length 1800mm is taken and it has been converted into a stepped shaft from one end of length 250mm and a diameter of 20mm is kept and the next 300mm length is made into 25mm diameter and from the other end a length of 250mm is made into a diameter of 25mm the rest of the shaft is kept at 30 mm diameter. Hybrid turbine made out of fibre-reinforced material so it is light in weight and can be made to rotate [14]. Height of the Savonius turbine is 250mm since it is used only for self-starting and the height of the Gorlov is 800 mm, diameter of both the turbine is 500mm and the no of blades used is 3 in Gorlov turbine because of the construction becomes simpler and the cost factor and also the solidity ratio can be managed. The helical blade in Gorlov kept at 120-degree angle between the starting and ending point of the blade. Is mounted on stand and placed in front of Axial Flow Turbine (wind tunnel)[17].

### 3.1 Specifications of Axial Flow Turbine

Height = 1m

Minimum Speed = 400rpm

Maximum Speed = 982rpm

Discharge = 11m/s

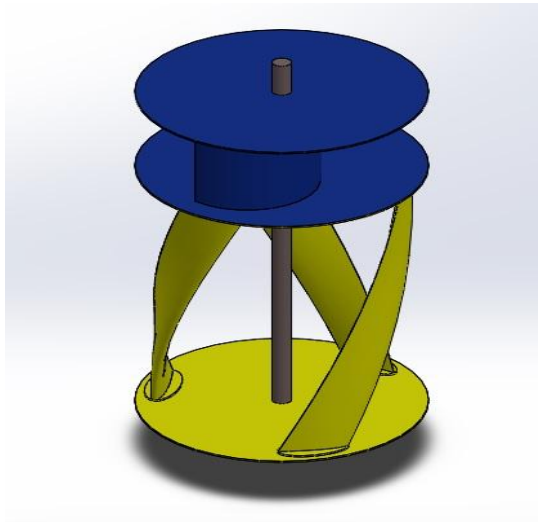


Fig. 1 Solid Work Model of Hybrid Vertical Axis Wind Turbine



Fig 2 Turbine mounted in the axial flow wind tunnel

## 4. CFD Analysis of Hybrid Vertical Axis Turbine

### 4.1 Simulation Properties & Conditions

Table 3 Conditions for CFD Analysis

Time scheme	Transient state
Material	Air
Properties of Fluid	
Density:	1.225 kg/m <sup>3</sup>
Kinematic viscosity:	1.7894e-5 kg/m-s
Compressibility:	Incompressible
Cell zone conditions	
Continuum type 1:	Fluid (blade rotational region)
Continuum type 2:	Solid (Turbine tower)
Blade rotational velocity	200 rpm
Blade rotational direction	Anti-Clockwise
Boundary Conditions	
Inlet Velocity	5m/s, 7m/s, 9m/s, 11m/s
Atmospheric pressure	1.01325 Bar
Turbine	Rotational, relative to the adjacent cell zone
Wall	Stationary wall, specified shear is zero

#### 4.2 Domain Details and Approach

The turbine is modeled in a generic domain to match the wind tunnel testing conditions in Fig 3. The length and width of the domain is 15m and 6m, and the height of the domain is approximately 12 times of the rotor [18].

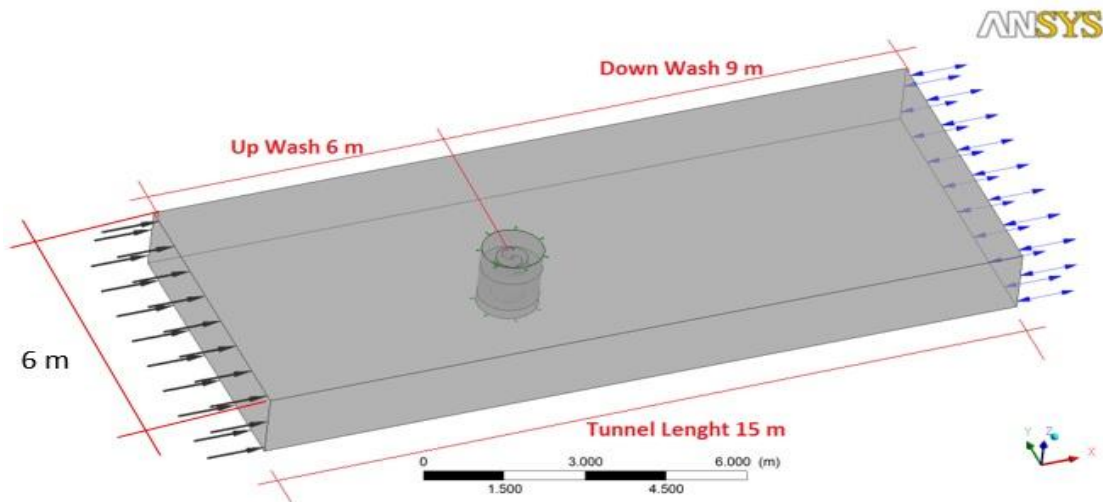


Fig. 3 CFD domains Configuration

#### 4.3 Torque Variation for Velocities

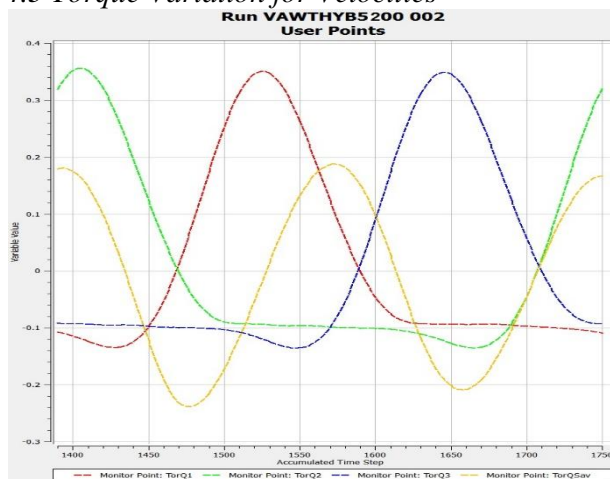


Fig. 4 Torque variation for velocities at 5m/s

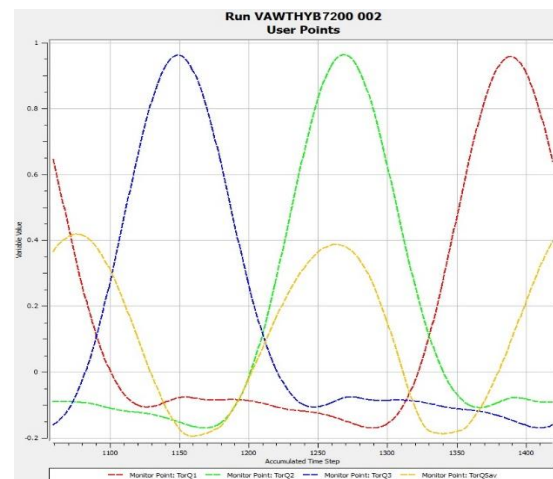


Fig. 5 Torque variation for velocities at 7m/s

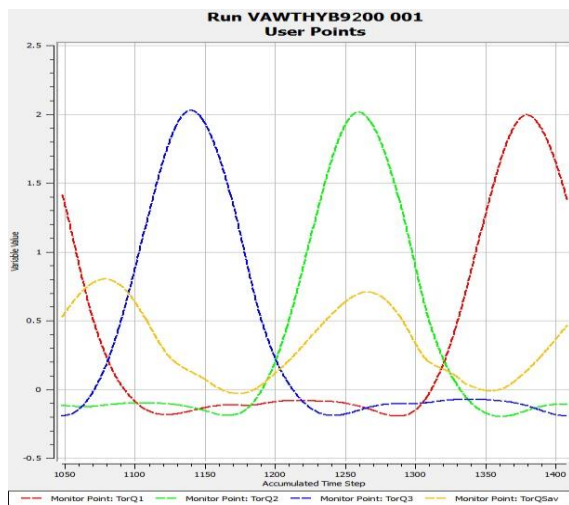


Fig. 6 Torque variation for velocities at 9m/s

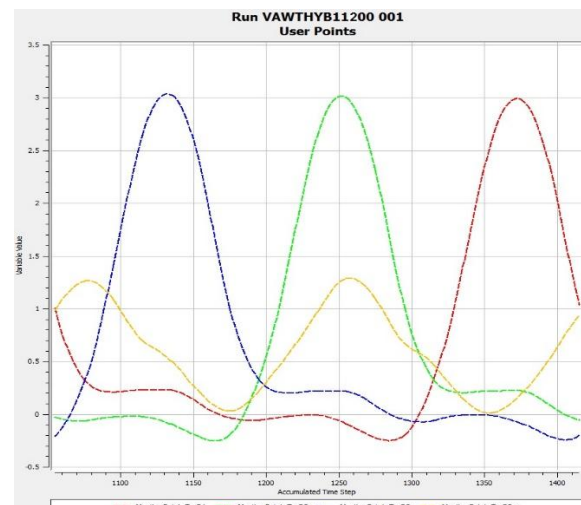


Fig. 7 Torque variation for velocities at 11m/s

This graph indicates the torque produced at varies angle of contact of the wind on the blade in fig 4,5,6,7. Yellow line on the graph shows the Savonius torque, the graph goes from top to bottom due to the shape Savonius turbine [16]. The Gorlov has 3 blades in it each blade gives a particular torque red line represents blade 1, green line represents the blade 2 and blue line represent blade 3. When the wind hits the blade 1, its observed that red line reaches the peak value. Similarly, when the wind hits the blade 2 and 3 it reaches its own peak value in the graph. These values of the peak are taken after leaving for few angles, so that it attains the constant values of the torque.

#### 4.4 Pressure Variation of Turbine

Pressure contour represents the pressure values at various point on the turbine. Here the observation shows higher zone to lower zone of pressure (we know that the flow of fluid takes place when there is a pressure difference) red zone indicates the higher pressure and blue line indicates the lower pressure. for Savonius is shown in fig 8 and Gorlov is shown in fig 9 So the wind flows from higher pressure zone to lower pressure zone so the turbine start to rotate the turbine.

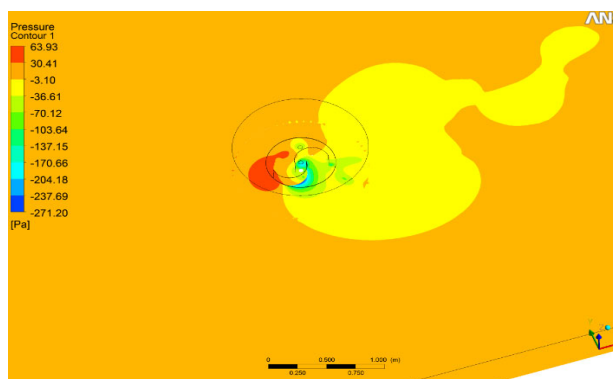


Fig. 8 Savonius Turbine

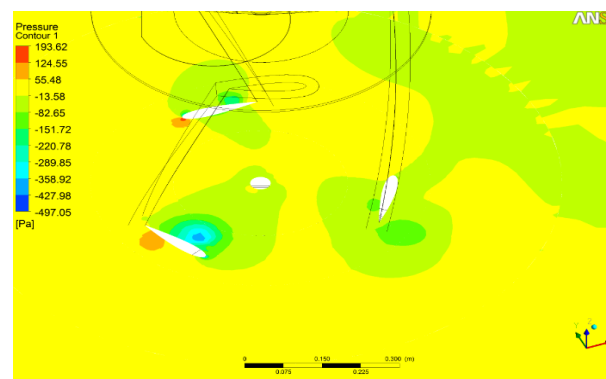


Fig. 9 Gorlov Turbine



#### 4.5 Velocity Variation of Turbine

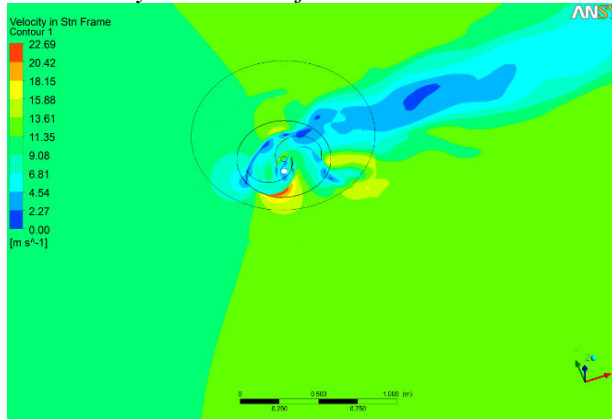


Fig. 10 Savonius Turbine

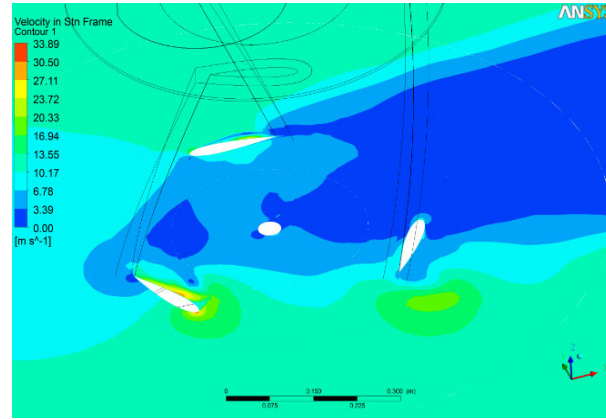


Fig. 11 Gorlov Turbine

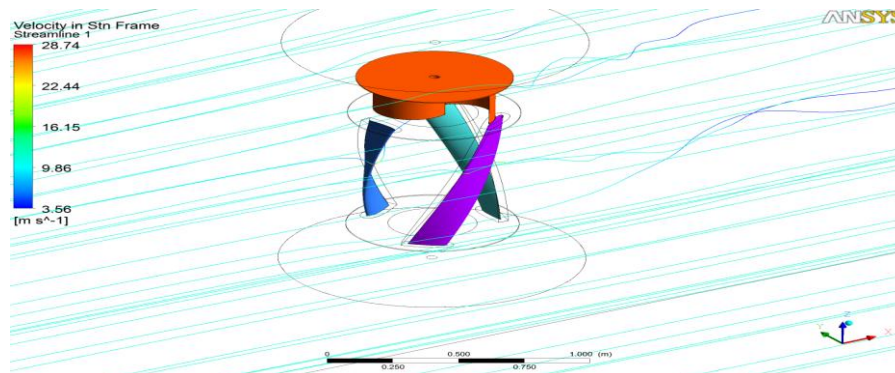


Fig. 12 Velocity Stream Line

Velocity stream line shows in fig 12 how the wind transmits its energy into the turbine for it to rotate[15]. Stream line shown in diagram, close observation gives the information that before hitting on the blades it has lost the kinetic energy while hitting on the blade and it is converted into the pressure energy. This will make the turbine to rotate there by the exit wind will have some loss in kinetic energy.

FOR 9 m/s

Torque = 1.358488 N-m (From Graph)

Speed N = 200 rpm

Angular velocity,  $\omega = 2\pi N \div 60 = 20.9439 \text{ rad/s}$

Tip Speed Ratio, TSR =  $\omega r \div v = 1.1635$

$P_{in} = 0.5\rho AV^3 = 234.419 \text{ watt}$

$P_{out} = T \times \omega = 28.4520 \text{ watt}$

$C_p = P_{out} \div P_{in} = 0.1213$



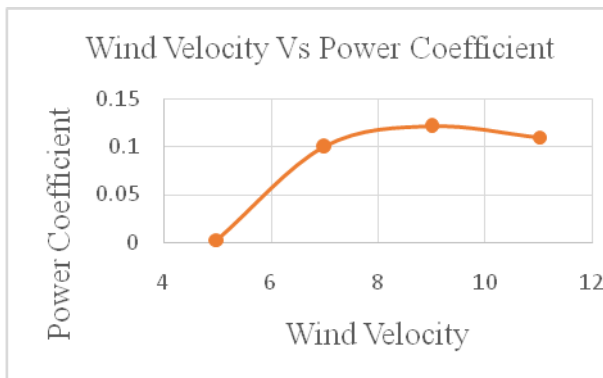


Fig.13 Wind Velocity Vs Power Coefficient

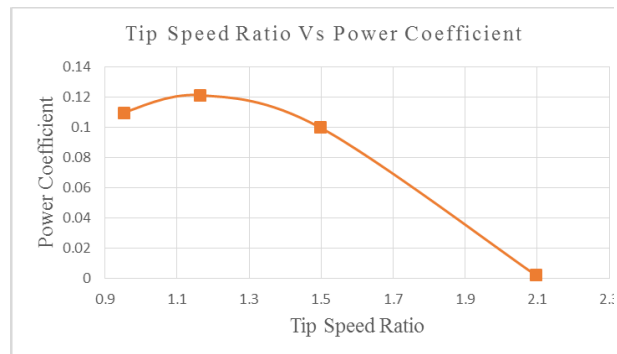


Fig. 14 Tip Speed Ratio Vs Power Coefficient

Fig 13 represents when the wind velocity increases the coefficient of power increases gradually and it reaches maximum and wind velocity further increases the coefficient of power decreases. This shows that at particular velocity only we can attain maximum coefficient of power and Fig 14 represents when the tip speed ratio increases the coefficient of power increases gradually and it reaches maximum and tip speed ratio further increases the coefficient of power decreases. This shows that at particular velocity only we can attain maximum coefficient of power.

## 5. Experimental Analysis

Calculation for 9 m/s

Torque = 0.07418 N-m (From Readings); Speed  $N = 201$

Angular velocity,  $\omega = 2\pi N \div 60 = 21.04 \text{ rad/s}$

Tip Speed Ratio,  $TSR = \omega r \div v = 1.1693$

$P_{in} = 0.5\rho A V^3 = 234.419 \text{ watt}$

$P_{out} = T \times \omega = 1.56074 \text{ watt}$ ,  $C_p = P_{out} \div P_{in} = 0.0066$

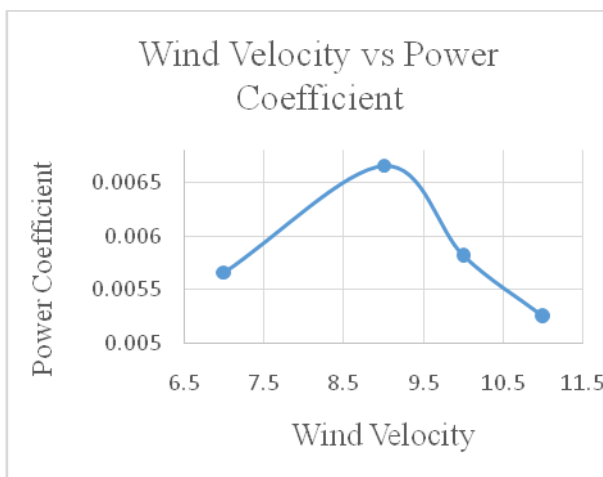


Fig. 15 Wind Velocity Vs Power Coefficient

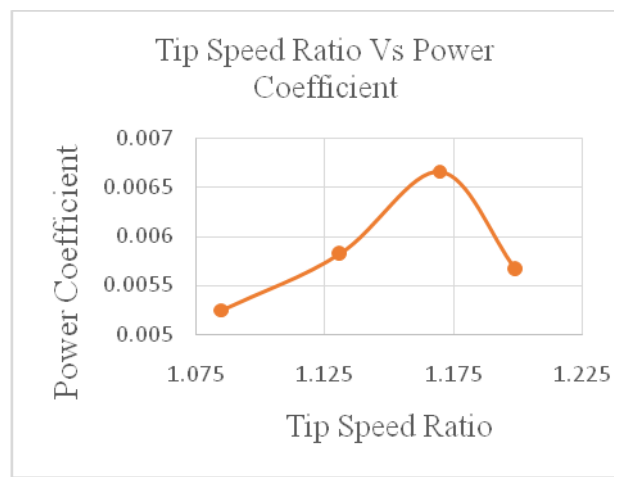


Fig. 16 Tip Speed Ratio Vs Power Coefficient

The above graph represents when the wind velocity increases the coefficient of power increases gradually and it reaches maximum and wind velocity further increases the coefficient of power

decreases. This shows that at particular velocity only we can attain maximum coefficient of power. The above graph represents when the tip speed ratio increases the coefficient of power decreases gradually. This shows that at particular velocity only we can attain maximum coefficient of power.

### 5.1 Comparison of CFD and Experimental Analysis

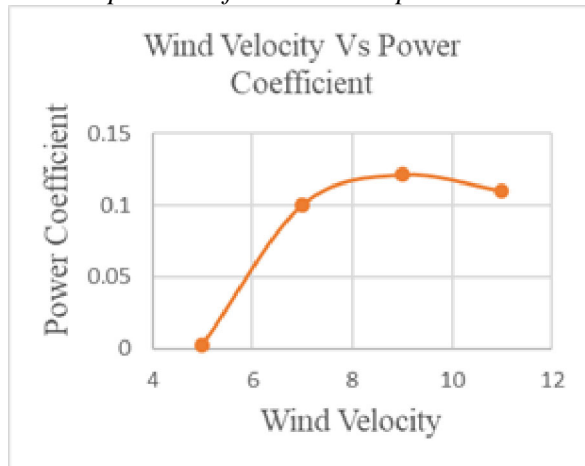


Fig. 17 Wind Velocity Vs Power Coefficient obtained from CFD analysis

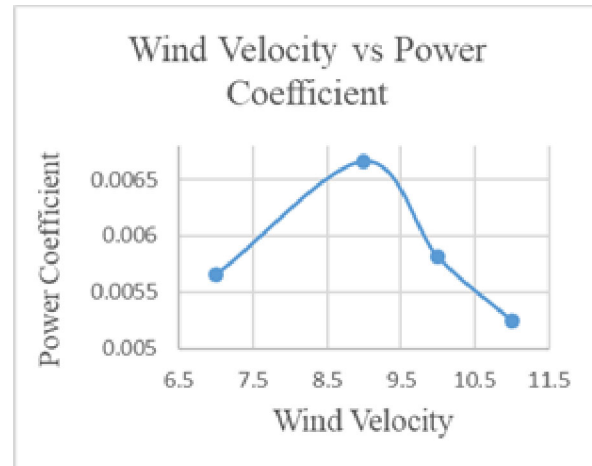


Fig. 18 Wind Velocity Vs Power Coefficient obtained by Experimental Analysis

Table 4 Comparison of Power Coefficient

Wind Velocity	CFD's Power Coefficient	Experimental Power Coefficient
7m/s	0.1001	0.00566
9m/s	0.1213	0.00666
11m/s	0.121	0.00525

#### Reasons for the Difference in Power Coefficient

1. In Experimental Analysis many losses to be considered such as

- Frictional loss
- Mechanical loss
- Environmental loss

2. In CFD Analysis the turbine runs with some boundary conditions where friction and other mechanical losses are neglected.

3. The difference in power coefficient depends on manufacturing of blade (aerofoil).

4. Blower efficiency and losses.

### 6. Conclusion and recommendation

The various results observed in experimental and Numerical study, which is based on various parameters such as speed, torque, velocity and coefficient of power. The values obtained are as follows:

Table 5 Observed Results

Experimental		Numerical	
<b>Speed</b>	215 rpm	<b>Speed</b>	200 rpm
<b>Torque</b>	0.07418 N-m	<b>Torque</b>	1.358488 N-m
<b>Velocity</b>	9 m/s	<b>Velocity</b>	9 m/s
<b>Power Coefficient</b>	0.00666	<b>Power Coefficient</b>	0.1213

The various coefficient of power obtained from the graphs, the analysis reveals that the velocity at 9m/s gives more efficient power for the particular design so this kind of turbines can be used in desert area.

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