Performance Testing and Analysis of Hexagonal Vertical Axis Wind Turbine

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Abstract: The study covers performance testing of Hexagonal Vertical Axis Wind Turbine (VAWT) designed and tested at Energy Center, Maulana Azad National Institute of Technology, Bhopal, India. Design and fabrication of a downsized model is a part of methodology for this study. Analysis of operation of a downsized Hexagonal VAWT model had been done at various wind speeds recorded at the Center. Average Cut –in speed the model and operating conditions shows that the model can be tested for large power generation. Computational study is done for mechanical power and power coefficient for different wind speeds.

Keywords: VAWT, Hexagonal turbine, Power Co-efficient, Mechanical Power, Tip Speed Ratio.

1. INTRODUCTION

Wind energy is that kinetic energy associated with the movement of large masses of wind. These motions are the result of uneven atmospheric heating by sun creating differences in temperature, pressure and density. Wind energy can be available for as much of 24- hours a day, though it may include no wind periods. In this case, the supply can be provided by the energy storage system. It is a clean, cheap, eco-friendly and reliable renewable source of energy. History of wind turbines dates back to 17th and 18th century A.D. It was in late 1800s when wind mills were used for electricity generation [1]. Recent research and developments came up with various types of wind turbines out of which Horizontal Axis Wind Turbines (HAWTs) and Vertical Axis Wind Turbines (VAWTs) are the most commonly used turbines [2]. Vertical Axis Wind Turbines have certain drawbacks that make HAWTs widely used commercially. These drawbacks are result of design of the VAWT, orientation of blades, the drag force acting on blades. To overcome these cons of VAWT, optimization of blades and development of efficient turbines is being done all over the world.

The focus of this research work is based on design of wind turbine such that it extracts power from a low wind speed. The concept of this structure was derived to prevent required wind pass through the rotor without interacting with the blades. Less noise level is expected due to low Tip Speed Ratio (TSR) [3].. Variation in power coefficients for different wind speed is analyzed. Power coefficient, C_p defines the efficiency of any wind energy conversion system (WECS) [4][6]. For a given swept area, there are factors affecting power generation, such as rotation velocity of rotor, turbulence created by blades, blade orientation [5]

The model rotor is such designed that it satisfies Betz criterion, which explains that at maximum power extraction condition, the upstream wind velocity is reduced to two third of the downstream velocity, in ideal case, and further to one-third of the downstream velocity, i.e., maximum value of power coefficient in an ideal case is 16/27 [6]. Practically, no wind turbine has a power coefficient more than or equal to 16/27.

2. THEORETICAL ANALYSIS OF WIND TURBINE

Wind turbine works on the principle of extracting energy from wind. The energy extracted is directly proportional to available wind speed.

A small Hexagonal VAWT model setup was placed on rooftop of the Energy Center building in MANIT, Bhopal, India. The parameters available as input data are wind speed, number of blades, swept area. Based on these primarily available data, important results are calculated, which describe the performance of a wind turbine.

Rotor Swept Area

The swept area is the section of wind enclosing the turbine in its movement. For HAWTs, swept area is circular in shape, while straight bladed VAWTs have rectangular shaped swept area. Swept Area, A (m^2), is given by:

$$A=2RL \quad (1)$$

Where, R = Rotor radius (m)

L = Length of the blade (m)

Power of the wind

Power of the wind (P_a) is the kinetic energy associated with the mass of moving wind[6].It is proportional to cube of wind speed.

$$P_a = \frac{1}{2}\rho A V^3 \quad (2)$$

Where ρ is Density of wind = 1.205 kg/m^3 and V is the wind speed in m/s.

Tip Speed Ratio

It is defined as the ratio of speed of extremities of turbine rotor to the wind speed. Mathematically,

$$TSR = \frac{R\,\omega}{V} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \qquad (3)$$

Generally, drag force acting on VAWTs results in low TSR, due to which rotation is slow.

Drag Force

The force exerted on the blades of turbine by wind along the direction of rotation of turbine is called Drag Force, denoted by F_D. Drag machines moves slower than lift machines. This is due to this reason that VAWTs are less efficient than HAWTs. Drag Force is given by

$$F_D = C_D\, \rho\, A\, V^2/2 \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \qquad (4)$$

Where, C_D is the Drag Coefficient.
$C_D = 0.5$ for Reynolds number, $R_e<10^5$
And 0.2 for $R_e>10^5$

Reynolds number is the ratio of inertia force to the viscous force.

Mechanical Torque developed by the Rotor

Torque is the product of force acting on the body and length of body on which force is acting. In case of a VAWT, mechanical torque, T, is developed by the rotor when drag force, from wind, acts along the length of the blade.

$$T = F_D \text{ X } L \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \qquad (5)$$

Where, L is the length of the blade (in meters)

Torque is proportional to length of the blade, which means VAWTs with broader blades can generate more torque than that with narrower blades. Torque also defines the amount of mechanical power generated by the machine.

Mechanical Power

The power generated by the mechanical device is its Mechanical Power. It is the product of torque developed by the rotor and the angular speed of the rotor.

$$P_m = \omega T \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \qquad (6)$$

Mechanical power is always less than power extracted by the wind. This is due to this reason Coefficient of Power is always less than 0.593 (Betz criterion).

Power Coefficient

The ratio of mechanical power, P_m, to power extracted by the wind, P_a, is known as Power Coefficient, C_p.

$$C_p = \frac{P_m}{P_a} \qquad (7)$$

In ideal condition, value of C_p do not exceed 16/27 or 0.593, according to Betz criterion. Power coefficient defines the efficiency of the wind turbine. Variation of power coefficient with respect to tip speed ratio characterize different types of rotor [7][8].

Methodology used in study

The developed model is a six-bladed structured vertical axis wind turbine erected on a tower with help of supporting structure. The blades of the turbine are pivoted to a hexagonal frame, with each blade as an extension of the adjacent sides of the hexagon.

Physical and technical specifications are listed in table 1.

Table 1

S. No.	Model Description		
	Particulars of parts	**Material Used**	**Quantity Used**
1.	Hexagonal Frame	Wood	1
2.	Blades	MS Sheets	6
3.	Supporting Frame	MS Sheets	1
4.	Erecting Tower	GI Pipes	1
5.	Gear Assembly	Spur Gear(07)	1

Fabrication of the model was done at MANIT, Bhopal. The enlisted particulars were assembled in accordance with modeling and designing of the model using auto-CAD.

The testing parameters of the Hexagonal VAWT model are listed as:

Rotor Radius : 0.35m
Length of the blade : 0.12m
Swept Area of the rotor : 0.084m^2
Total Height of the model : 1.62m

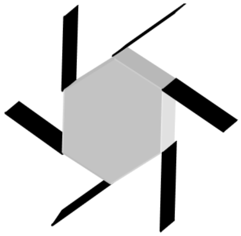


Fig. 1. 3D view modeling of turbine

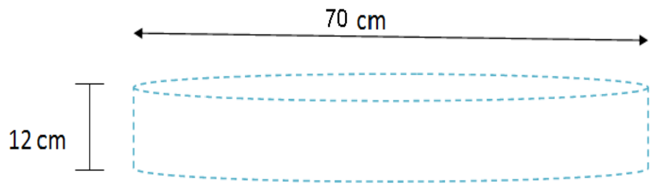


Fig. 2. Swept Area Covered by rotor

Fig. 2. shows the area swept by the rotor of the model while rotation. In VAWTs, the shape of swept area is rectangular which is defined by length of blade and rotor radius.

Using (1), swept area of the model is calculated

A = 2RL

= 2 X 0.35 X 0.12 = 0.084 m^2

Hexagonal Frame

The main emphasized structure of the model is the frame of hexagonal shape. The frame is made of wood, covered with a layer of molten mild steel to prevent it from atmospheric moisture and termites. Each side of the hexagon measures 0.21m. For blades to be attached to the frame, the edges are raised to a height of 0.06 m.

Blades

Blades acts as the driving force from wind exerts on them. These rotating blades are attached to the hexagonal frame in such way that no wind passes through the gap between them. The six blades, attached as extension to each edge of frame, are made up of mild steel sheets. Individual width of each blade is 0.3m and a length of 0.12m.

Chord of blades is such designed that a little amount of lift force acts on the surface of blade to help it move comparatively faster.

Erecting Tower

Made up of galvanized iron pipes of 0.7m diameter, the 1.58m tower rests on the ground as a tripod tower. Distance between legs of the tower is maintained to balance the machine while rotating without any vibration. The weight of tower is also taken into consideration as it has to bear the weight of the frame with blades.

Supporting Frame

Most important feature of VAWTs is a supporting structure. For large VAWTs, supporting guy wires are used to make it stand erect. For a downsized model of VAWT, supporting frame can be used for the same. This model uses a supporting frame made of mild steel sheet, in conical shape with both ends open. The larger opening is attached with frame with axis of cone perpendicular to the base of hexagonal frame.

3. RESULTS AND ANALYSIS

The performance testing of the hexagonal VAWT model was done at rooftop of Energy Center, MANIT Bhopal, India, 23.2500° N, 77.4167° E, 430 m above sea level.

Based on these primary data, computational study is done to obtain the performance efficiency of the model.

Wind data for various rotor speed were recorded using a digital anemometer installed in the center. Table 2 shows the results obtained by computational methodology.

The computational study involved (1) to (7).

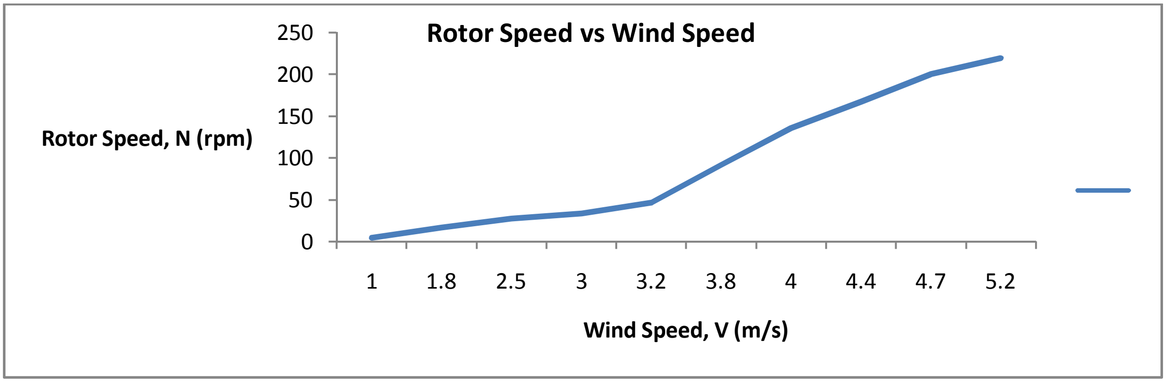
It shows the variation in values of power from the wind is much more than that of mechanical power. This is due to the fact that a lot of power is consumed in rotating the turbine. Power in the wind is proportional to cube of wind speed while mechanical power is proportional to lower degree of wind speed and more on the dimensional factors of turbine, hence there is difference in amount of power extracted from wind and mechanical power generated by the turbine.

Table 1 Results of computed parameters

Wind Speed, V (m/s)	Rotor Speed, N (rpm)	Computed parameters			
		Power in the wind, P_a (watts)	Mechanical power, P_m (watts)	Tip Speed Ratio, TSR	Power coefficient, C_p
1	5	0.051	0.003	0.183	0.063
1.8	17	0.295	0.018	0.346	0.059
2.5	28	0.791	0.056	0.41	0.07
3	34	1.367	0.097	0415	0.071
3.2	47	1.658	0.153	0.538	0.092
3.8	92	2.777	0.423	0.889	0.152
4	136	3.239	0.694	1.249	0.214
4.4	168	4.311	1.037	1.403	0.24
4.7	201	5.254	1.415	1.572	0.269
5.2	220	7.116	1.89	1.549	0.2656

Rotor Speed

The speed of the rotor, N, was recorded for different wind speeds using a tachometer.



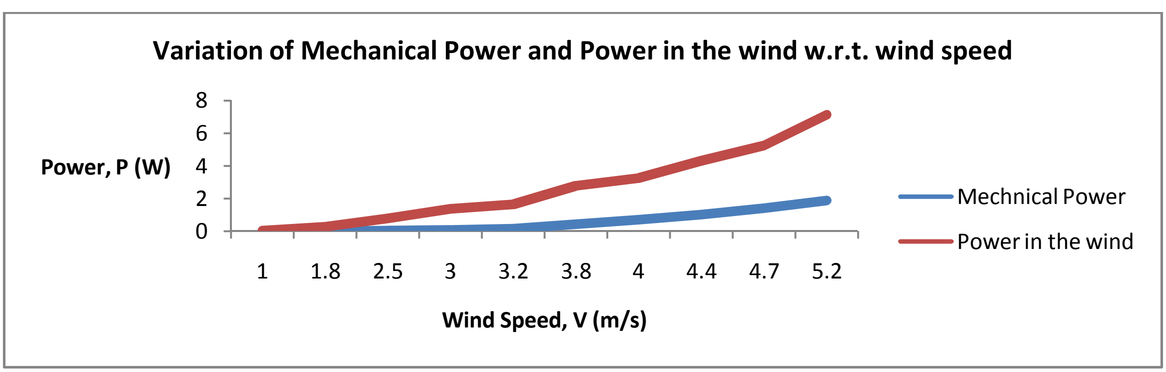
The experiment observation for rotor speed recorded values from a low of 5rpm to a high of 220rpm. As there is increase in wind speed, the rotor speed rises gradually and with a threshold momentum, there is a sudden rise in rotor speed at about V = 3.5m/s. This sudden rise also accounts for steep changes in other mechanical factors.

Power from the wind and Mechanical Power

Power extracted from wind is proportional to cube of wind speed, so there is an exponential increase in the value of P_a. The power from wind was calculated using (2), and recorded at range of 7.116 W. The low value of P_a reflects the low swept area of the turbine

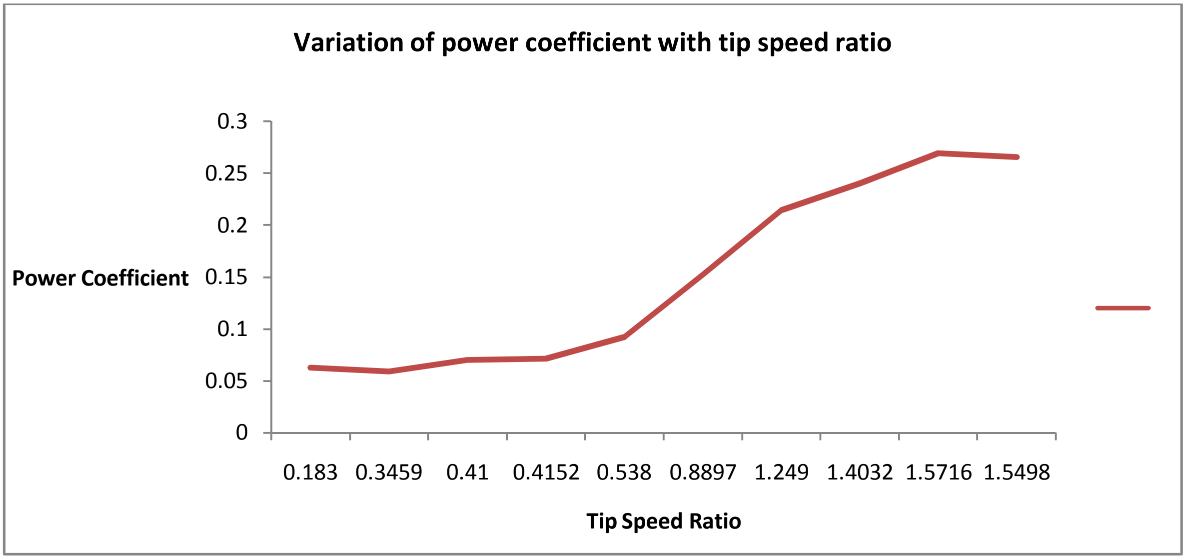
As all the power from wind can not be converted to mechanical power, i.e., no machine has an efficiency of 1, Mechanical power is always less than power extracted from wind.

Mechanical power was calculated using (6) and highest value for P_m obtained is 1.89 W.



Power Coefficient

The power coefficient, maximum value of which is 0.593 for ideal machine, shows the efficiency of performance of the wind turbine. For various recorded wind speeds, power coefficient is obtained in a range of 0.059, for V = 1.8 m/s, to 0.269, for V = 4.7 m/s.



4. CONCLUSION

For a downsized highest power coefficient obtained, mathematically, is 0.269. This is a satisfactory result as far as the size of the model and availability of wind is concerned. Moreover, materials used in manufacturing of turbine also play an important role in determining the performance of a wind turbine. Hence, it can be said, after the experimental study of Hexagonal VAWT, that there is a genuine scope of power generation using this type of wind turbine at a larger scale. Analytical studies and further developments can confer a more sustainable, reliable and commercial status to Hexagonal VAWT.

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