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Research Article

Design and Fabrication of Flipping Blade Vertical Axis Wind Turbine

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Abstract

Wind energy is one of the renewable sources, used to generate an electric power generation. The search for environment friendly, sustainable energy has promoted in this industrial world. The present global technological society is depended on the availability of energy. The development of industry, agriculture and transportation, etc. is totally depended on the availability of power. The cost of energy is increasing day by day due to the increase in the demand of power and depletion of the resources, which are used in the generation of electricity. So, it is very essential to make use of the non-conventional sources of energy like wind energy, solar energy, tidal energy, etc. Wind energy is used to generate electrical power by rotating the rotor shaft by the conversion of kinetic energy of wind into rotational energy of the shaft. The performance of wind turbine can be increased by increasing the drag force on the blade. This paper introduces a new mechanism developed by us and this mechanism is used to change the blade position during running condition to increase the resultant drag force on turbine blade. This mechanism is simple and also decreases cost of wind turbine by using flat blades.

Keywords: *Renewable sources, Vertical Axis Wind Turbine, Wind Energy, Flat blade*

1. Introduction

There has been an enormous increase in the global demand for energy in recent years as a result of industrial development and population growth. Supply of energy is, therefore, far less than the actual demand.

Adequate availability of inexpensive energy is the most important demand of today. Economic growth and industrialization both are dependent on the availability of energy. But today the problem is that world energy sources are fast depleting and these fast depleting energy resources have put the world in a grip of energy crisis. This is the time to take steps to conserve the conventional sources and also find the alternative sources of energy such as solar energy, wind energy, tidal energy, geothermal energy etc. to generate the power.

A significant amount of exhaustive research has been done in the area of small and medium scale wind turbine blades and most of them have used the classical blade element momentum theory for designing the blades and calculating the forces acting on it. Lot of research on finding the optimum chord lengths has been made using a variety of evolutionary optimizing techniques. Some work that forms the background for this research is as follows. Mahri and Rouabah had calculated the dynamic stresses on a blade which was designed using the blade element theory. The rotor diameter was 10 meters and the dynamic analysis was made using the beam theory and the modal analysis is made using the finite element modeling and also using the blade motion equation. Mickael Edon had designed a blade for 38 meters for a 1.5MW power using the BEM theory, and had suggested in his future work the chord distribution formula.Philippe Giguere and Selig had described blade geometry optimization for the design of wind turbine rotors, pre-programmed software was used to optimize structures and cost model. Jureczko, Pawlak, Mezyk used the BEM theory to design and used ANSYS for calculation of natural frequencies. They had found out the mode shape of the blades by using the Timoshenko twisted tapered beam element theory. The genetic algorithm was used to minimize blade vibration, maximize output, minimize blade cost and increase stability.

Tingting Guo, Dianwen Wu, Jihui Xu, Shaohua Li developed a 1.5 MW turbine rotor of 35 meters blade length, using Matlab programming for designing and concluded the feasibility of Matlab for designing large wind turbines, further they had also compared with CFD results and the found out Matlab was economical in artificial design and optimizing for efficiency. Carlo Enrico Carcangiu used CFD tool FLUENT to a better understanding of fluid flow over blades.

Jackson, et.al made a preliminary design of a 50 meters long blade, two versions one of fiber glass and one with carbon composite was used to test the cost and thickness of cross sections was changed in order to improve structural efficiency. The aerodynamic performance was made using computational techniques and the computations were predicted using clean and soiled

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surface. Wang Xudong, et al used three different wind turbine sizes in order to optimize the cost based on maximizing the annual energy production for particular turbines at a general site. In their research using a refined BEM theory, an optimization model for wind turbines based on structural dynamics of blades and minimizes the cost of energy. Effective reduction of the optimization was documented. Karam and Hani optimized using the variables as cross section area, radius of gyration and the chord length, the optimal design is for maximum natural frequency. The optimization is done using multi dimensional search techniques. The results had shown the technique was efficient.

From this literature survey, we observed that research is going on the profile of blade and effect of number of blades to increase the wind mill performance. The performance of wind turbine power plant depends on the performance of wind turbine. But the performance of wind turbine depends on profile of blade, number of blades and drag force acting on the blade. This paper, we provive a new mechanism to increase the drag force on the blade as it will increase the performance of wind turbine.

2. Flipping Blade Vertical Axis Wind Turbine

The analysis is carried out on Flipping Four Blade Vertical Axis Wind Turbine. It is a drag based wind turbine. Wind acts on the flat blades thus pushing them and rotating the rotor shaft connected to the blades. The rotor shaft is then connected the generator through a gear box. The vertical axis wind turbine (VAWT) is suitable for low wind speeds. It produces high torque and does not require starting thrust.

The components of this turbine are same to other turbines, but it consists additionally flipping construction. Components of this turbine are mentioned below.

2.1. Blades: The blades are made up of aluminum bars and plastic sheet. The Aluminium bars are fabricated in such that they act as the frame for the polystyrene sheet. Weight of Aluminum is light with a density one third of that of steel. Strength of Aluminum is strong with a tensile strength of 70 to 700MPa depending on the alloy and manufacturing process. The length of the blade is 9 m, height is 2ft and width is 0.36 m. Clamps are used to fix the blades to minor shaft. Two clamps are used to fix each blade to minor shaft. One blade is fixed as horizontal and other as vertical position.

2.2. Flipping Blade Construction: The flipping mechanism used in VAWT is a unique mechanism designed by us. This mechanism is used to change the position of the blades during its operation to increase the resultant drag force on the turbine blades. The flipping of the blades is the most important improvement in the turbine. This changing the position of the blades helps in increasing the total drag force procured from the wind.

This turbine has been so designed that each blade flips an angle of 90o before and after coming in contact with the wind. The flipping mechanism does not require any external energy source to change the direction of blades during turbine operation. It is totally dependent on the rotation of the rotor shaft. The flipping construction consists of following parts:

2.2.1. Levers: It is made up of Galvanized iron pipe. It is shown in the figure 1. Long screws and bolts are also used for the adjustment of lever on the on the minor shafts. There are four levers used in this turbine. Each Minor Shaft has two levers which are fixed by bolt and screws. Levers flip the blades when it strikes on metal disc.

Fig.1 Levers

2.2.2 Structural Metal Disc and L-Clamps: It is made up of Iron. Metal Disc has indefinite shape. Shape of this disc is shown in the figure 2. Thickness of Metal Disc is 8mm. This Structural Metal Disc is supported by L-shaped supporting clamps. L-shaped supporting clamps are fixed to tower there by supporting the Structural Metal disc. The L- clamps are fixed to levers by using bolts and nuts. The combination of structural metal disc and L- clamps are shown in fig.3.

Fig.2 Structural Metal Disc

Fig.3 Structural Metal Disc & L-Clamps

2.2.3 Supporting Clamps: A Circular Metal Disc made up of iron is fixed to the tower at the top of the tower(1feet down from top of the tower) as shown in fig.4. L-shaped supporting clamps are fixed to this Circular Metal Disc using bolts and nuts to get a very rigid support. Two L-shaped clamps are used in this turbine.

Fig.4 Supporting Clamps

2.3 Tower: It is very important part of the turbine. It is 10feet long. It is made up of hallow Galvanised iron pipe. Bearings are fixed to ends of the tower through which a main shaft is arranged. This shaft is connected to gear box. There are two rectangular projections to this tower which are used for handling the tower and they can also be used to provide support to the tower using wires. Circular disc is fixed to the tower at the top.

2.4 Base: This is main support for the entire Flipping Four Blade Vertical Axis Wind Turbine unit. It is made of Iron. Thickness of iron used is 4mm. It has rectangular shape, supported by four legs. It has circular hole at the centre where the tower is placed. It is made very rigid to provide very good support and with stand high wind speeds. Base is very well welded and extra blots and nuts are fixed to provide the extra support.

2.5 Main Shaft: It is important part in the power transmission system of the turbine as shown in fig.5. It is made up of Iron. It is 1feet longer than tower. Main Shaft is made to pass through the tower using two bearings. These bearings allow the main shaft to rotate freely when blades rotate. Main Shaft is connected to the hub at one end and to the gear box at another end.

Fig.5 Main Shaft

2.6 Minor Shaft: There are two Minor Shafts in this turbine. Minor Shafts are made up of hallow Galvanized iron pipe. Each Minor shaft is made to pass through the hub as shown in the figure 9 using two bearings. These bearings allow the Minor Shafts to flip easily when the levers strike the Structural Metal Disc. Each Minor Shaft is 9 feet long. Blades are fixed to these Minor Shafts using clamps. Each Minor Shaft has fixed two blades.

2.7 Hub: Hub is used to connect the main shaft and minor shaft. Hub is very rigidly fixed at the top of tower. It is made up of Iron. These clamps fix the blades to the minor shaft. The total construction of VAWT is shown in fig.8.

3 Types of Forces Acting on Blade

When the air flows arrive to the leading edge, the flows separate into the upper and lower surfaces of the airfoil. The distance from the leading edge to the trailing edge on the upper camber is longer than for the lower camber. In order to meet at the trailing edge at the same time, the flow's velocity on the upper camber is higher than the flow's velocity on the lower camber. From the Bernoulli equation the pressure on the upper camber is lower that the pressure on the lower camber. This pressure variation creates a lift and a drag force. The drag force is also due to the viscous friction between the air flow and the airfoil. The lift force is perpendicular to the direction of the relative velocity, while the drag force is parallel with relative velocity. This is shown in the figure below. These two forces result in the creation of the thrust force and the torque force (moment force). The thrust force is perpendicular to the plane of rotation of the turbine while the torque force is tangential to the circular path of the rotation of the turbine.

When the blade is at an angle, then the total force created by the wind is converted into drag and lift on the blade.

Total Force = Drag force + lift force (1)

So when the blade is vertically placed, the total force is converted into drag force.

Total force = Drag Force (2)

This drag force moves the turbine rotor by pushing the blades which are facing the wind.

The lift and drag force are caused due to the relative motion of the wind. The formula for the lift force can be written as $F_L=C_L(\frac{1}{2}\rho A U_{rel}^2)$ (3)

Where, F_L = Lift Force in N

ρ = Density of air in Kg/m^3 ($1.254\ kg/m^3$ at 15ºC)

C_L = Lift Co-efficient

A = Swept Area in m^2

U_{rel} = Relative Velocity of the Wind in m/sec

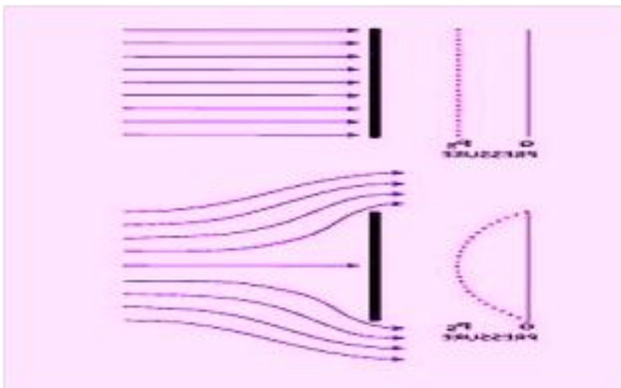

Fig.6. Wind acting on the vertical Blade

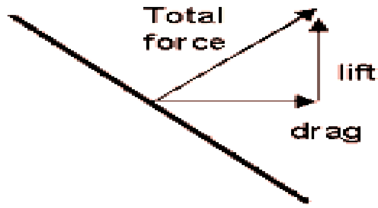

Fig.7. Vertical Blade at an inclination

The formula for the drag force can be written as
$F_D = C_D(\frac{1}{2}\rho A U_{rel}^2)$ (4)

Where, F_D = Drag Force in N
C_D = Drag Co-efficient

The relative velocity is the vector sum of the free stream and the rotational wind velocity.

$U_{rel} = U + \Omega r$ (5)

Where, U = Free Stream Wind Velocity in m/sec
r = Radius of the Blade, m

$U_{rel} = \sqrt{U^2 + (\Omega r)^2}$ (6)

4 Formulation

The following formulae are used in the analysis of VAWT.

4.1 Swept Area

The swept area is the section of air that encloses the turbine in its movement, the shape of the swept area depends on the rotor configuration, this way the swept area of an HAWT is circular shaped while for a straight-bladed vertical axis wind turbine the swept area has a circular shape and is calculated using:
$A = \Pi r$ (7)
The swept area limits the volume of air passing by the turbine. The rotor converts the energy contained in the wind in rotational movement so as bigger the area, bigger power output in the same wind conditions.

4.2 Power and Power Coefficient

The power available from wind for a vertical axis wind turbine can be found from the following formula:
$P_w = (\rho A V^3)/2$ (8)
Where, V = Velocity of The Wind in m/sec
P_w = Power Available From Wind in Watts

Note that available power is dependent on the cube of the airspeed.
The power the turbine takes from wind is calculated using the power coefficient:

$C_p = \frac{\text{captured mechanical power by blades}}{\text{available wind power}}$ (9)
Where, C_p= Power Coefficient

Cp value represents the part of the total available power that is actually taken from wind, which can be understood as its efficiency. There is a theoretical limit in the efficiency of a wind turbine determined by the deceleration the wind suffers when going across the turbine. According to Lanchester-Betz limit the efficiency of HAWT is 59.3% and for VAWT is 64%. These values come from the actuator disk momentum theory which assumes steady, in-viscid and without swirl flow.

4.3 Wind Turbine Efficiency

Rotor power efficiencies were calculated using the formula:
$\text{Efficiency} = \eta_{wt} = \frac{\text{Power of wind turbine}}{\text{Power available in the wind}}$ (10)
Where, η_{wt} = Wind Turbine Efficiency in %

5. Results and Discussions

The wind turbine has four blades which are connected to the minor shafts. These minor shafts are assembled into a hub. The minor shafts are fitted in such a way that they have a property of revolving in one direction on their axis of rotation. In the fig 8. the positions of the blades are shown as 1,2,3 and 4 positions. The two blades are fitted on the same minor shaft as one blade is in vertical and other is at horizontal. Similarly, two blades are fitted on other minor shaft. The position of blade changes from horizontal to vertical and vice-versa with the help of flipping mechanism. This mechanism is explained as follows.

At position 1, the blade is in contact with the wind but, it creates minimum drag as the L-clamp of minor shaft starts contact with the metal disc. So, the alignment of the blade is maintained in the horizontal position.

At position 2, the blade is in horizontal position. The clamp is sliding on the disc. The sliding motion maintains the same blade position until the L- clamp leaves the contact of the disc.

At position 3, the blade is in vertical position. It is facing the wind and produces maximum drag. The other end of the same shaft has another blade is in horizontal position.

At position 4, the blade is in vertical position. This blade is not in contact with the wind and thus produces negligible drag on the blade.

In position 1 and position 3, the blades are in contact with the wind. The blade at position 1 creates minimum drag as it is in horizontal and the blade at position 2 creates maximum drag as it is in vertical. Thus, the resultant drag force on the blades increases.

5.1 Transmission System: The transmission is used to transmit the power developed at the wings to the generator.

Transmission linkage consists of blades as power developing elements and minor shaft and hub to transmit the power to the major shaft which is connected to the hub. Later major is shaft connected to the gear box. Then gear box is connected to the generator.

The elements of the transmission are

1. The Hub
2. The main shaft
3. The gear box

Fig.8. Positioning of the Blades

The blades are attached to the minor shafts. These are attached to the hub. The main rotor shaft is locked to the hub. The minor shaft rotates the hub, the hub then rotates the input shaft of the gear box.

The resultant drag produced by the blades rotated the main rotor shaft. The shaft is connected to the input shaft of the gearbox. The gearbox converts the high torque low rpm into high rpm low torque.

5.2 Observation

The following readings have been observed in practical conditions.

S.No.	Wind Speed(m/s)	Tip Speed	R.P.M
1	0.5	No Motion	0
2	1	No Motion	0
3	1.5	Movement Started	0
4	2	1.19	4.6
5	3	2.48	9.8
6	4	3.562	13.7
7	5	4.498	17.3
8	6	5.59	21.5
9	7	6.48	24.8

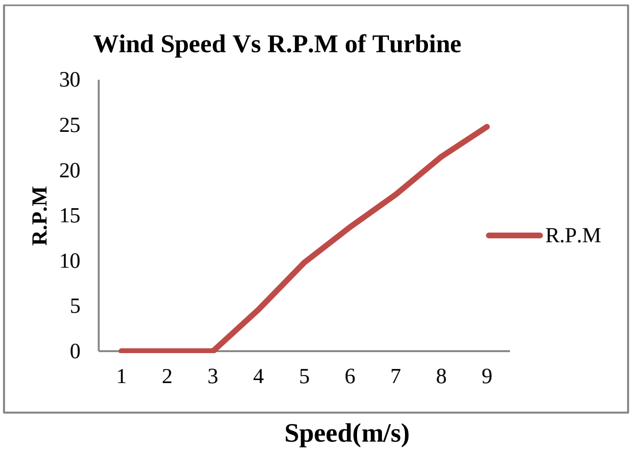

Fig.9 Speed Vs R.P.M

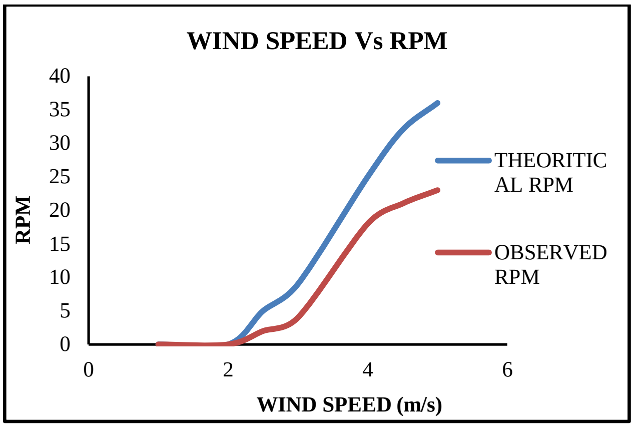

Fig.10 Wind Speed Vs Theoritical & Observed R.P.M.

- From Fig.9, it is observed that R.P.M of wind turbine increases as wind speed increases.
- From Fig.10, it is observed that at higher wind speed, the RPM values of theoretical & observed come to closure.
- From Fig.11, it is observed that speed increases, drag force on the blade also increases in both flippling VAWT and Savonius turbine. But it shows that the drag force developed on flippling VAWT is more than the Savonius turbine

.

Conclusions

In this paper, a new concept of flipping mechanism of vertical axis wind turbine is introduced that rotates the turbine at low wind speed and it is observed that turbine starts it's rotation at a speed of 2m/sec with 4 rpm. This mechanism is used to change direction of blades and develop more drag force while turbine is rotating. It is observed that drag obtained by our vertical axis wind turbine is more than the Savonius turbine.

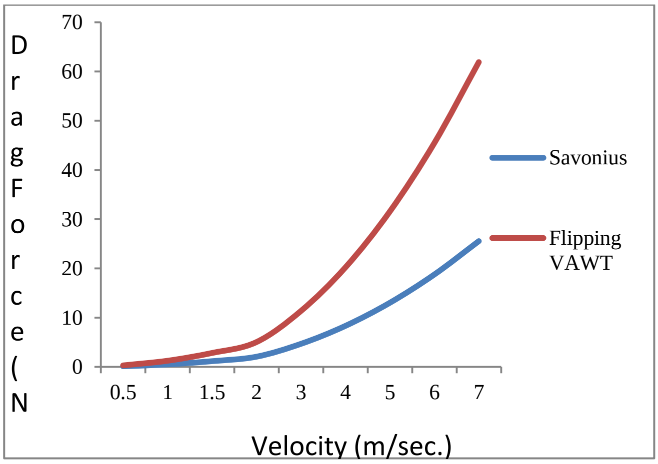

Fig.11 Wind Speed Vs Drag Force

The analysis is yielding with the following conclusions.

1. Rotates the turbine at low wind speeds.

2. Manufacture of blades are easy.
3. It produces high torque and does not require starting thrust.
4. More drag force is developed from wind energy.
5. More mechanical work is developed by the turbine.
6. Low cost as manufacture of blade is simple.

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