Modification of Straight Bladed Hallow Cored Wind Turbine Through Experimental Analysis

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Abstract: ***The main aim of this research is to develop an efficient small wind turbine for domestic power generation in remote areas like rural, island areas, etc. The vertical axis wind turbine was chosen because of it reacts to wind from any direction, and low cost for small energy needs. The number of U.S patents was studied and for the research hallow cored wind turbine was selected which was invented by Matthew Leo Ruder in 2012. The research is carried out on straight bladed hallow cored wind turbine in order to improve its efficiency. The eight vertical axis wind turbine models were investigated. These eight models are fabricated by using Aluminum sheet metal and tested in wind tunnel at various wind speeds. In the wind tunnel tests, the effect of number of blades and helical angle on efficiency is examined. The results are noted in a tabular column and the graphs are plotted for coefficient of power and coefficient of torque against wind speed. By comparing these results, it is found that the three bladed double helical hallow cored wind turbine (DHHCWT) with helical angle 30^0 has maximum efficiency of about 8.84%.***

Keywords: hallow, cored, wind turbine, helical, eight.

1. Introduction

In the continuous research of clean, safe and renewable energy sources, the wind energy is one of the best attractive solutions. The focus on Renewable Energy Resources has increased significantly in the recent years increasing of environmental pollution, rising energy demand and depleting fossil fuel resources. Different sources of renewable energy include biomass, solar, geothermal, hydroelectric, and wind. Among these resources wind has proved to be a cheaper alternative energy resource and hence extensive research efforts have been put to improve the technology of electricity generation through wind. Wind energy is the form of solar energy that can be converted in to mechanical (rotational) energy and again the mechanical energy can be converted in to electrical energy by means of generator.

2. Literature Review

2.1 Hallow Cored Wind Turbine

Commonly, vertical axis wind turbines are divided in to two types. They are the savonuis wind turbine, darrieus wind turbine. Savonius has vertical half cylindrical blades and it is a drag type wind turbine. Darrieus wind turbine has egg beater blades that have a flat side and a curved side to create the lift. The air flowing over the airfoils (wind turbine blades) is converted into rotational energy which rotates the generator. In the vertical axis wind turbine swept area is a cylinder perpendicular to air flow. The efficiency can be improved by improving the swept area of the wind turbine rotor. The challenge in a vertical axis wind turbine design is to optimize the shape and angle of the blade to minimize the drag caused by the blades not facing into the wind. A turbine blade designer, Matthew Leo Ruder, (2012) invented "Straight bladed Hallow cored wind turbine". It is a combination type wind turbine which consists of both positive drag forces and lift forces. The hallow cored means the inner core part is empty. By this reason these blades are weight less compared to the conventional wind turbine. In hallow cored type of wind turbine blades; there are two types of drag forces acting on the blade surface. First type of the drag force is parallel to the relative wind. And another type of the drag force is opposite to the relative wind. The "Hallow cored wind turbine Wings" are simply constructed using aluminum and fiber glass to form the airfoil blades.

2.2 Numerical Parameters

The numerical parameters of the Hallow cored wind turbine are

The blade width = 0.14 x D

The chord length of the blade = 0.08 x π x D

Where, D= Diameter of the wind turbine in meters

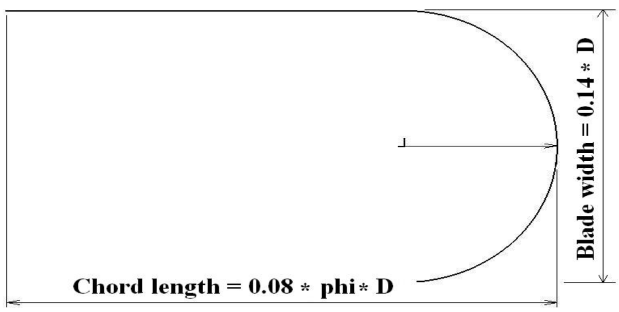


Figure 1: Standard dimensions of the Hallow cored wind turbine wind turbine.

3. Experimental Tests

3.1 Basic Concepts

1. The swept area = $A_S = H * D$
2. Tip speed ratio = TSR = $\frac{\omega * R}{V}$
3. Torque = $F * r$
4. The Torque Coefficient (C_T) = $\frac{T}{T_W}$

$$\frac{\text{The rotor torque}}{0.5 * \rho * A_S * R * V^2}$$

5. Power coefficient (C_P) = $\frac{P_E}{P_a}$

$$\frac{T * \omega}{0.5 * \rho * A * V^3}$$

3.2 Physical model description

The model is the small scale replica of the actual machine / equipment or structure .All the blades are fabricated by using aluminum sheet metal of 30 gauge thickness. These vertical axis wind turbine are fabricated as per the standards of the Matthew Leo Ruder scientist. It is a straight bladed vertical axis wind turbine with hallow cored blades. The height and diameter of the wind turbine model (H & D) is 20 cm. And the rotor was mounted on central aluminum shaft of 10mm diameter; the height of the shaft is 38 cm. Hallow cored wind turbine blade can easily made by combing half cylindrical sheet metal and sheet metal plate. This type of blade is weight less and low cost and less raw materials are required for fabrication. These blades are connected to the shaft by means of circular aluminum plate or spokes.

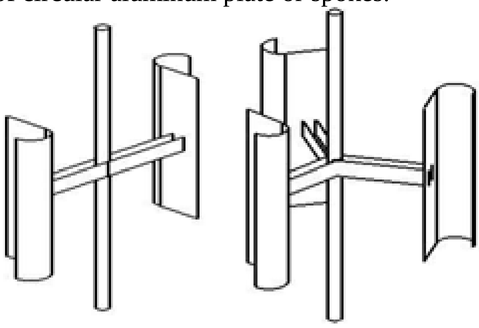


Figure 2: Two and three bladed hallow cored models.

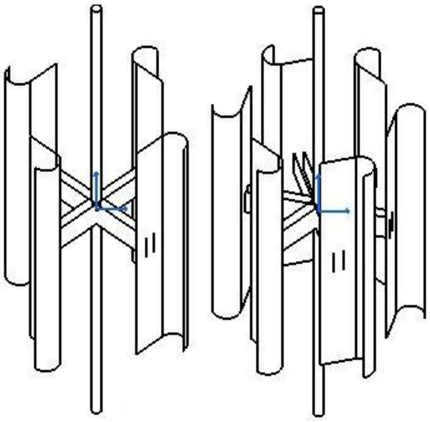


Figure 3: Four and five bladed hallow cored models.

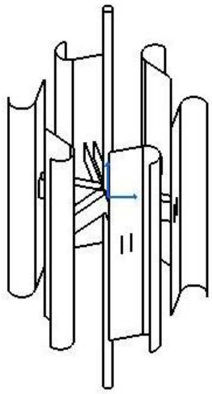


Figure 4: Six bladed hallow cored model

The two bladed hallow cored wind turbine model consists two blades and each are separated by 180^0. The three bladed hallow cored wind turbine model consists three blades and each are separated by 120^0. The four bladed hallow cored wind turbine model consists four blades and each are separated by 90^0. The five bladed hallow cored wind turbine model consists five blades and each are separated by 72^0. The six bladed hallow cored wind turbine model consists six blades and each are separated by 60^0.

3.3 The wind tunnel

Wind Tunnel is a device for producing airflow relative to the body under test. Wind tunnels provide uniform flow conditions in their test section. Experiments were conducted in an open circuit subsonic wind tunnel available in the R&D cell. The size of the wind tunnel test section was 40 cm x 40 cm, and length of the test section was 1 meter. It consists of centrifugal fan, damping chamber, settling chamber, test section, diffuser, etc. The operating range of the wind tunnel was 0-12 m/sec. The wind tunnel was operated by a centrifugal fan having 10 kW capacity motor that supplies 5500 cubic feet per meter at rated 2800 rpm. The turbulence intensity of the wind tunnel was around 1%. The Air Speed Regulator is used to control the air speed flowing through the wind tunnel.

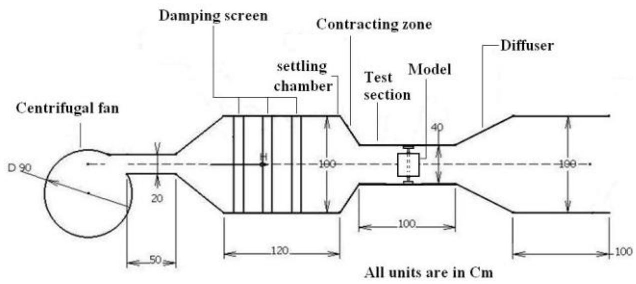


Figure 6: Schematic layout of open circuit subsonic wind tunnel.

3.4 The Measuring Instruments

1. **Anemometer:**
   It is used to measure the wind speed and it is commonly used in weather station. It represents Wind velocity in (m/sec). I used a vane type anemometer and its capacity is 0 to 30 m/sec.

2. **Photo - contact tachometer:**

It is used to measure the rotational speed of the rotor. This device generally displays the revolutions per minute on a display. And its capacity is 4000 Rpm.

3. Rope brake dynamometer:
   It is used to measure the torque produced by the rotor of the wind turbine. It is the oldest and simplest method to determine the torque of the wind rotor. It consists of plastic pulley, spring balance, weighting pan, rope, etc.

3.5 Experimental Procedure

1) Take the wind turbine model and properly place it in the wind tunnel test section.
2) In such a way that the two ends of the shaft is inserted in to the frictionless bearings.
3) The mechanical power for the wind turbine models is calculated by measuring the mechanical torque on the rotating shaft and rotational speed of the shaft.
4) The testing arrangement contains plastic pulley system, nylon string of 1mm diameter, weighing pan and spring balance, etc.
5) The torque is measured by simple rope brake dynamometer and by using weights hanged freely around a pulley which is mounted on the rotating shaft by adding weights gradually until the shaft fully stopped.
6) By using air regulator switch, we can select appropriate wind speed that is 2 to 10 m/sec.
7) For every model, first find out the cut-in speed of the wind turbine model by using digital anemometer.
8) And also measure the rotational speed of the wind turbine by using laser digital tachometer.
9) And find out the speed and torque at different wind speeds (up to 10 m/sec)
10) Note the values in a tabular column for further calculations.
11) Calculate the power, $C_{P,}$ C_T by using the above formulas and also draw the performance graphs of the wind turbine models.

3.6 Effect of number of blades on efficiency

The graph shows the relation between the coefficient of power and wind speed (2 to 10 m/sec) for two, three, four, five and six bladed hallow cored wind turbine models. According to the Matthew Leo Ruder standards, we can place up to 2 to 6 blades in each configuration of wind turbine. The wind tunnel tests are conducted in order to find out the number of blades for optimum efficiency. By conducting wind tunnel tests, it is found that the average efficiency of two bladed hallow core wind turbine is 6.6 %. The average efficiency of three bladed hallow core wind turbine is 7.8 %. The average efficiency of four bladed hallow core wind turbine is 7.46 %. The average efficiency of five bladed hallow core wind turbine is 7.4 %. And the six bladed hallow core wind turbine has average efficiency of about 7.5 %. It was seen that the coefficient of performance of the three bladed hallow cored wind turbine (straight bladed) model is high when compared two, four, five and six bladed models. This may be due to on increasing the blades number the torque is decreasing simultaneously because of the net drag force affected on the wind turbine blades. Therefore, by comparing the results, it is concluded that the three bladed hallow cored wind turbine model has high efficiency.

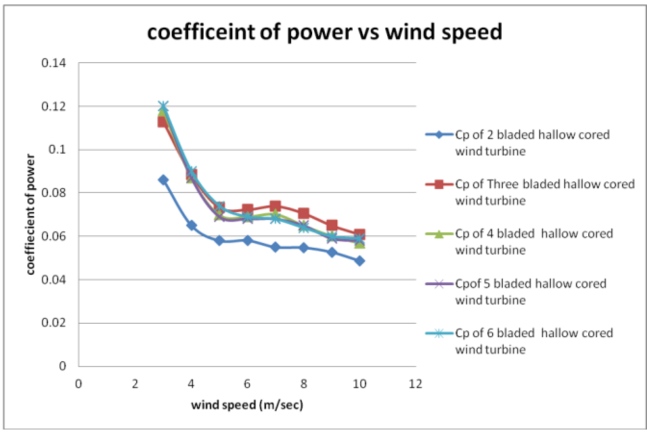


Figure 7: Coefficient of power of the wind turbines VS Wind speed

4. Double helical hallow core wind turbine:

We know that, the power in the wind = P = ½ ρ A v^3.

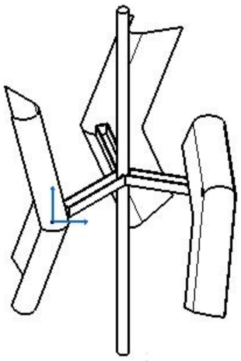
1) P α A (swept area of the rotor).
2) P α v (velocity of the wind).

There are three factors which determine the output from a wind turbine.
a. The wind speed.
b. The swept area of the turbine rotor.
c. The overall conversion efficiency of the rotor, transmission system and generator.

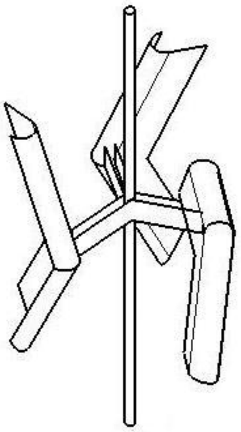
By considering the swept area factor, we know that the power available in the wind is directly proportional to the swept area of the turbine. If the swept area of the wind turbine is increased, automatically the efficiency of the wind turbine is also increases. Therefore, the blades are designed in the shape of double helical.

4.1 Physical model description

It consists two half helical blades. The first half is counter clock wise helical blades are connected to the second half clock wise helical blade. It increases the swept area of the rotor. It has two helical angles so, it is named as double helical hallow cored wind turbine. These blades are connected to the shaft by means of circular aluminum plate or spokes. It is necessary to find out at which helical angle gives optimum efficiency. The double helical hallow cored wind turbine is investigated by changing the helical angles from 20^0 to 40^0. These double helical wind turbines are fabricated by using aluminum sheet metal of 30 gauge thickness. The height and diameter of the wind turbine model (H & D) is 20 cm. The rotor was mounted on central aluminum shaft of 10mm diameter; the height of the shaft is 38 cm. And each blade is separated by 120^0.



a)



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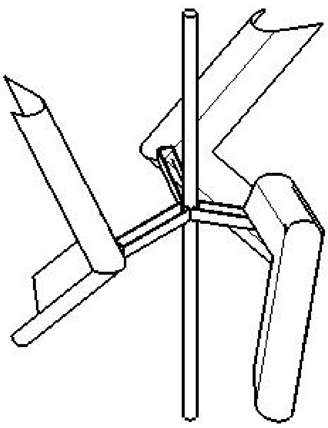

c)

Figure 8: Three bladed double helical (20^0, 30^0,40^0) hallow cored wind turbine models

a) Figure Double helical (20^0).
b) Figure Double helical (30^0).
c) Figure Double helical (40^0).

These three double helical hallow cored wind turbines are tested in the wind tunnel. And the values are noted in a tabular column for calculation of the performance of the wind turbines at different helical angles.

4.2 Effect of double helical angle on efficiency

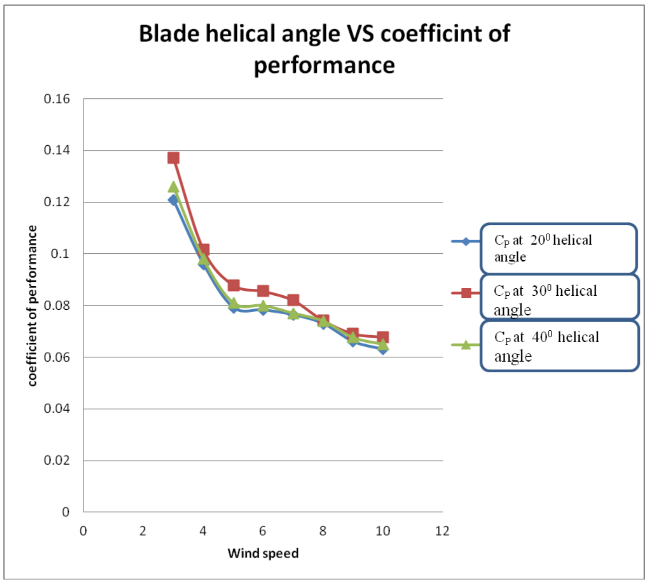

Figure 9: Representing the coefficient of the performance of the double helical (20^0,30^0,40^0) hallow cored wind turbines versus wind speed

Figure 9 shows the relation between the coefficient of power and wind speed (m/sec) for double helical (20^0,30^0,40^0) hallow cored wind turbine. The average efficiency of three bladed Double Helical (20^0) hallow cored wind turbine model is 8.15%. The average efficiency of three bladed Double Helical (30^0) hallow cored wind turbine model is 8.84%. The average efficiency of three bladed Double Helical (20^0) hallow cored wind turbine model is 8.36%.By comparing the results it is found that "at helical angle 30^0 " gives optimum efficiency. And an overall 1.04% of efficiency is increased then three bladed straight hallow cored wind turbine. Therefore, it is concluded that the three bladed double helical (30^0) hallow cored wind turbine is efficient than other models.

4.3 Coefficient of power of the wind turbines VS Wind speed

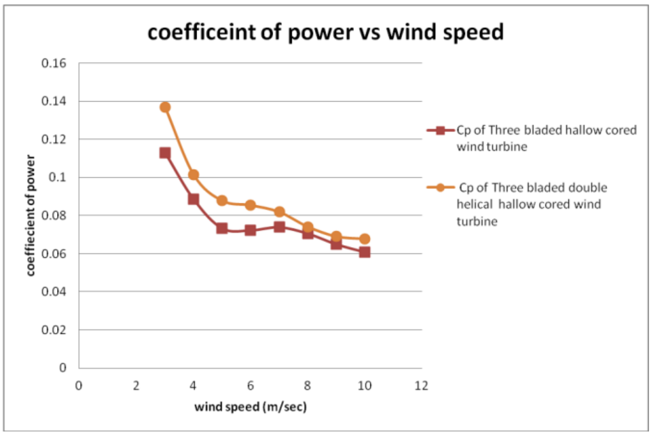

Figure 10: Coefficient of power VS Wind speed

Figure 10 shows the relation between the coefficient of power and wind speed (m/sec) for three bladed hallow cored wind turbine model and three bladed double helical (30^0) hallow cored wind turbine model. By conducting the wind tunnel tests, it was seen that the three bladed double helical hallow cored wind turbine has high coefficient of power when compared to three bladed hallow cored wind turbine model. And an overall 1.04% of efficiency is increased then the three bladed hallow cored wind turbine model. Therefore, it is concluded that the three bladed double helical hallow cored wind turbine is efficient than other models.

4.4 Coefficient of torque of the wind turbines VS Wind speed

Figure 11 shows the relation between the coefficient of torque and wind speed (m/sec) for three bladed hallow cored wind turbine and three bladed double helical hallow cored wind turbine model. By conducting the wind tunnel tests, it was seen that the three bladed double helical (30^0) hallow cored wind turbine has high coefficient of torque when compared to three bladed hallow cored wind turbine model. The static torque plays important role in the performance of every wind turbine.

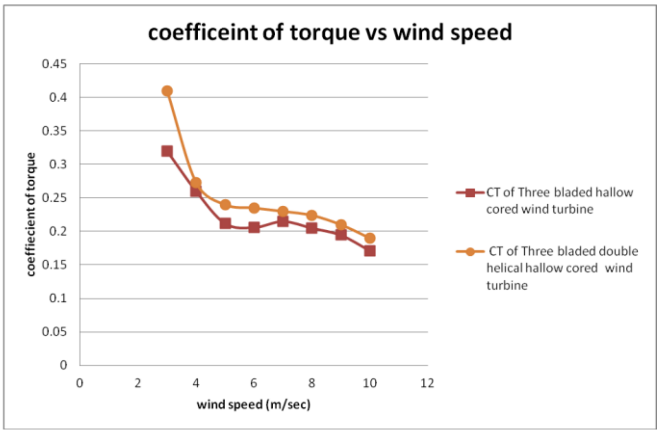

Figure 11: Coefficient of torque of the wind turbines VS Wind speed

5. Conclusion

From the research, the following conclusions can be summarized.

- The coefficient of performance of the three bladed hallow cored wind turbine (straight bladed) model is high when compared two, four, five and six bladed models.
- This may be due to on increasing the blades number the torque is decreasing simultaneously because of the net drag force affected on the wind turbine blades.
- The optimum number of blades for straight bladed hallow core wind turbine is three.
- The average efficiency of three bladed hallow core wind turbine is 7.8 %.
- The blades are designed in the shape of double helical, in order to increase the swept area of the rotor.
- The optimum helical angle for double helical hallow cored wind turbine is 30^0.
- Both coefficient of power and Coefficient of torque are increased than straight bladed hallow cored wind turbine.
- The average efficiency of three bladed Double Helical (30^0) hallow cored wind turbine model is 8.84%
- And an overall 1.04% of efficiency is increased then three bladed straight hallow cored wind turbine.

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