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Design, Fabrication and Testing of Straight Blade H-Darreius Vertical Axis Wind Turbine

Noman Ali[1], Tanweer Hussain[2], Intizar Ali Tunio[3], Nisar Ali[4]

[1,]Research student, Department of Energy System Engineering, MUET, Jamshoro
[2,3]Department of Energy System Engineering, MUET Jamshoro

Abstract: Vertical axis wind turbines (VAWTs) have been recognized as a promising solution to harness wind energy due to their ability to operate effectively in turbulent wind conditions. However, traditional VAWTs have limitations in terms of low efficiency and start-up speeds. There are also limited studies for studying turbine behavior in open atmosphere. To address these challenges, straight-blade H-Darrieus VAWTs have been proposed. In this study, turbine is designed, fabricated and tested in open atmosphere with the aspect ratio of 1:4. To analyze torque and power performance of the straight blade vertical axis wind turbine for (5.7 m/s) wind speed at different tip speed ratios i.e 1.4-2.6 were tested. The Anemometer is used to measure wind speed and simple torque measuring mechanism also introduced to measure torque. Study concluded the effect of tip speed ratio for torque and power performance of the turbine. The turbine can be improved further for better performance in open atmosphere by changing some design parameters or by reducing bearing friction.

Keywords: *Straight Blade, Tip Speed Ratio, Torque and Power Performance Analysis*

1. Introduction

In this era, the energy is considered to be the crucial component for human activities, whereas fossil fuels are considered as main source of energy nowadays but due to negative effect on the environment and emits greenhouse gases which causes to climate change and global warming[1].

Wind energy considered a key technology for mitigating the impacts of climate change, as it produces no greenhouse gas emissions during operation. It also provides many other benefits such as reducing dependence on fossil fuels, creating job and improving energy security [2]. A turbine's blades are rotate by the wind and converts kinetic energy into mechanical which spins the generator to produce electricity[3].

There are two types of wind turbine horizontal and vertical axis wind turbine where the vertical axis wind turbine attracts more intention due to ease in maintenance and does not required yaw mechanism and can also work in low and turbulent wind areas but the term "horizontal axis" refers to the rotation's axis being parallel to the direction of the entering wind, V. This arrangement now rules the large-scale wind generation industry, production mutually on land and offshore due to its significant power coefficient and comparatively minimal structural blade loading[4]. With TSRs less than 0.5, 3-PB and helical-blade VAWTs have similar amounts of average and variation of the overall torque coefficient. For instance, at the TSR of 0.44, the average of total torque coefficient produced by the 3-PB turbine is 6.06% higher than that of helical-blade VAWT. Further, the deviation of total torque coefficient of 3-PB VAWT is 22.48% less than that of helical-blade VAWT[5]. In previous studies the mostly used profiles for H-Darrieus turbines are symmetrical NACA00xx profiles, specifically NACA0018, NACA0015 and NACA0012.

Initially, aerodynamic design and theoretical power prediction for vertical axis wind turbines (VAWTs) were based on aerofoils developed for aviation. These aerofoils were well understood, and data were readily available for a variety of conditions, which made design and prediction relatively straightforward. However, researchers soon realized that these aerofoils might not be optimal for VAWT applications[6]. Specially constructed blades, such as cambered profiles, laminar flow aerofoils or greater thickness profiles, could be employed to increase turbine performance. Furthermore, NACA0021 profile performs better at low tip speed ratio, DU06W200 profile displays maximum power coefficient at low tip speed ratio, and NACA44115 profile fails under all situations. Number of studies showed that initial or starting process will be completed when turbine starts to produce useful output. Precisely it does not have any surety that turbines may continuously to accelerate once the blades start to generate lift over the most part of rotation. Recently, the turbine has been deemed self-starting only if it can changes from rest to the TSR where thrust is generated constantly over the Darrieus flight path [7].

The power performance of twin vertical axis wind turbines was studied by altering their shape parameters with the aid of computational fluid dynamics simulations (CFD). The model was verified using data from other studies' wind tunnel tests. Via a variety of instances, the Taguchi method and parameters were used to maximize the power

Corresponding author Email address*: rananomanrajput46@gmail.com*

performance of the turbine. Here, the twin VAWTs' best and worst configurations were identified, along with their corresponding values, by 13% and 8%, respectively. Its TSR ratings differed from their CP ratings[8].

Moreover, the several design parameters that affect the self-starting, power coefficient, and performance of vertical axis wind turbines have been evaluated and optimized. It has been discovered that using a superior pitch position blade technique will improve self-starting capability and power performance. The greatest power performance for TSRs between 0.5 and 3 provided as a result of the variation in pitch angle between 45° and 10° with six distinct blade pitching curves[9].

The swept area and wind speed, not the blade area, determine how much power is generated by a wind turbine. A single blade turbine is thus potentially as efficient as two or three blade turbines. According to the proportion of wind kinetic energy that can be extracted and transformed to mechanical power. However, at low speeds, a single blade is unable to produce a forward torque at the maximum azimuth angles, making it impossible for the machine to self-start[6].The solidity of an H-Darrieus wind turbine is described as the blade length to the radius of the turbine blades relation and the number of total lades[10].

The developing countries like Pakistan where electricity is not provided to many areas such small scale VAWT are beneficial for household. Pakistan is also putting in wind projects to address its energy crisis. Another resource with an average speed of 5 to 12 m/s is wind, which is a plentiful source of clean energy. One such place is Sindh province's Gharo wind corridor[11]. In the end of 2014, Pakistan's installed wind capacity was close to 106 MW; however, by the end of 2018 and 2019, it had climbed to 1186 MW and 1236 MW, respectively.

Pakistan's Renewable Energy Policy 2019 states that by 2025 and 2030, it wants to generate 25 and 30 percent of its total energy from renewable sources[12]. Particularly in the constructed environment, small VAWTs are regarded as one of the maximum capable methods of producing clean electricity. The air flows in that environment. However, are categorized by abrupt changes in direction and velocity since wind speeds there are frequently low and variable with significant degrees of turbulence. Due to its less effect of wind direction, ease of maintenance, easy blade shape, low sound and low price, vertical axis wind turbines (VAWTs) have been identified as more considerable than the other used horizontal axis wind turbines (HAWTs) in these circumstances[13].

It is noted that straight blade H-Darreius VAWT are simple to design, manufacture, and installation also requires very low cost, however these turbines have major problems like low power coefficient and poor self-starting characteristics. Rather than manufacturing complicated turbines present study aim to experimentally investigate power coefficient and torque performance of H-Darreius turbine through the proper selection of design parameters in open atmosphere. This study is performed at the Mehran university of engineering and technology Jamshoro.

2. Modeling of VAWT

The first objective of this research was conceptual design and to create a CAD model of the turbine. After selecting the parameters, the CAD model was developed in the Solid Works 2015 designing software. The coordinates of the NACA 0021 airfoil were exported into solid works software. After having the sketch of the airfoil, it was extruded to form the blade and copied to meet the desired number of blades. After that the central strut and the connecting arms were made from sketches and extruded into 3D objects and hence the assembly was completed to make the CAD model of the turbine. The used parameters are given below:

Table:1. Turbine design parameters

Airfoil		**Airfoil NACA0021**
No: of blades	N	3
Chord length	C	100 mm
Height	S	400 mm
Diameter	D	600 mm

From the CAD modeling the different views of turbine are obtained which are given below.

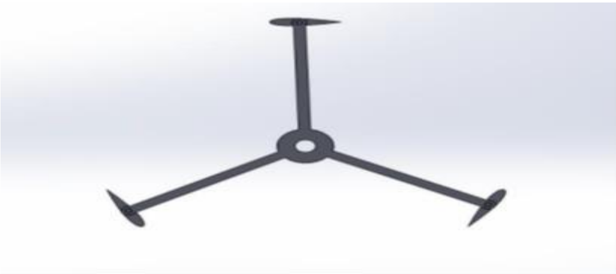

Figure.1. Top view of H Darreius VAWT

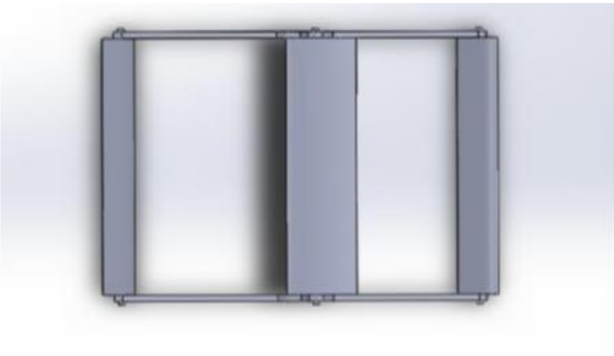

Figure.2. Front view of H Darreius VAW

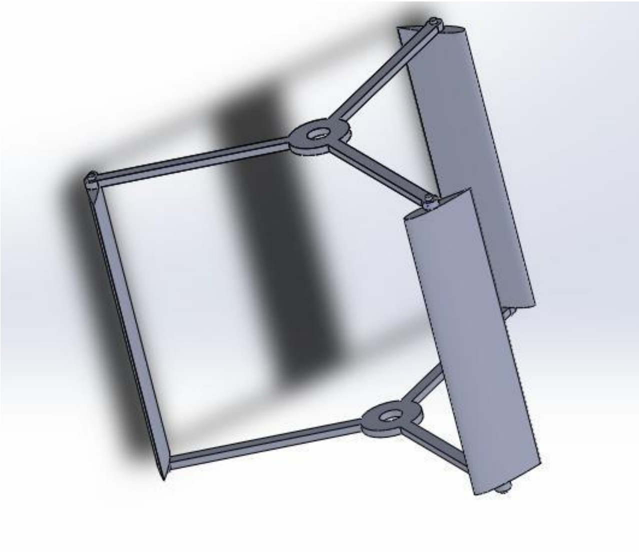

Figure.3. Auxiliary view of H Darreius VAWT

3. Fabrication

Mainly the turbine consists of different parts i.e blades, arms and central shaft. where NACA0021 profile has large thickness that shows best performance of the turbine. Where the 3 blade configuration is also best suited to self-starting and power extraction from the wind. The fabrication of turbine and its frame are being fabricated in the welding shop of Mehran university of engineering and technology Jamshoro. Whereas the frame is fabricated to carry turbine.

3.1 Fabrication of blades

The structure of the blade is made up of two parts: (I) an internal part (frame), which consists of three profile pieces (NACA0021), and a flat cast iron, (ii) an external part made up of a covering metal sheet. The profile pieces and flat cast irons were fabricated from 2D sketches. The sheet was first cut into outline of the NACA0021 shape (100mm in the chord). The profile pieces were manufactured from aluminum. Then the flat cast irons were welded to the profile pieces (two profiles at the ends and one in the center). Once the frame was complete, a covering metal sheet was cut from the aluminum. Finally, the sheet was wrapped around the frame and welded to give the final blade.

3.2 Fabrication of arms

The connecting arms are mainly made up of mild steel which are designed at lathe machine. These arms are used to connect blades with central rotor shaft. Here the total number of arms is 6, where each two arms are connected at the end of each blade with bolts. These arms are connected rectangular in cross section and fixed to center shaft with arc welding.

Figure.4. Fabrication of blades, Arms and Rotor Shaft

3.3 Fabrication of center shaft

The center shaft is hollow shaft where another shaft should go through it to fasten it in any wind testing criteria either in tunnel or in atmospheric conditions. The center shaft is made up of mild steel at lathe machine by facing and turning of the shaft at desired length and diameter.

3.4 Turbine assembly

For testing turbine, the metal frame is made. The frame is made up of rectangular metal pipes simply known as L angles which are welded together by arc welding. With the help of frame, the turbine can be tested anywhere at any place in open atmosphere. To place turbine in frame two bearings are connected to the turbine rotor shaft as the turbine rotates easily inside the frame where the bearing at the lower part supporting the weight of the turbine by acting as thrust bearing. The installed turbine assembly is shown below in figure 5.

Figure.5. H-Darreius Turbine Assembly

3.5 Torque measuring mechanism

The pulley was connected to the rotating shaft. So the belt was wrapped around the pulley. where its one end was connected to the spring balance and one end of belt was connected with movable nut, which moves steadily when angular forces induced in turbine due to the rotation of blades and readings were taken. The nut can be moved with different loads depends upon the wind speed or force induced due to rotation. This basic mechanism was used to measure torque easily and shown in figure 6.

Figure.6. Torque measuring mechanism

4. Results and Discussion

The turbine is tested in open atmosphere and found results are shown over graph to understand turbine performance. In open atmosphere the 5.7m/sec wind speed is found. The effect of tip speed ratio for torque and power coefficient is discussed below.

4.1 Toque Performance

When wind strikes blade it produces angular velocity in the shaft and also the force. Initially the torque was calculated from torque mechanism and turbine torque coefficient is calculated numerically which is then plotted on graph to understand turbine behavior. From the graph it is noted that the torque is high at low tip speed ratio because at low tip speed ratio the maximum wind passes through the turbine. With the increase in tip speed ratio the blades start to rotate in a disk form which in result reduces the torque shown in figure 7, whereas the turbine torque performance is directly depends upon torque. As the torque reduces, the torque coefficient will also be reduced it means the torque performance has inverse relation with tip speed ratio shown in fig 8. It is noted that the low range of TSR is better for torque coefficient or torque performance of turbine in open atmosphere.

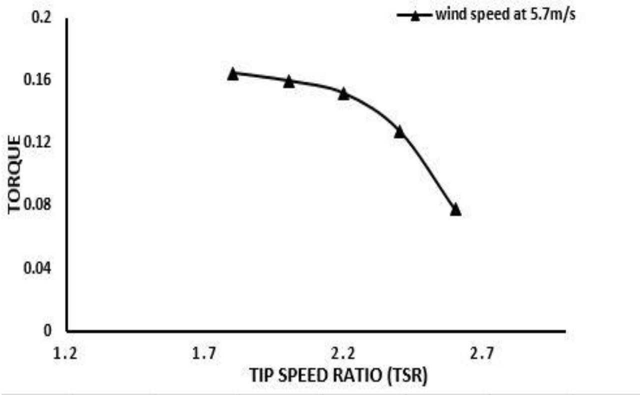

Figure.7. Torque vs Tip speed ratio

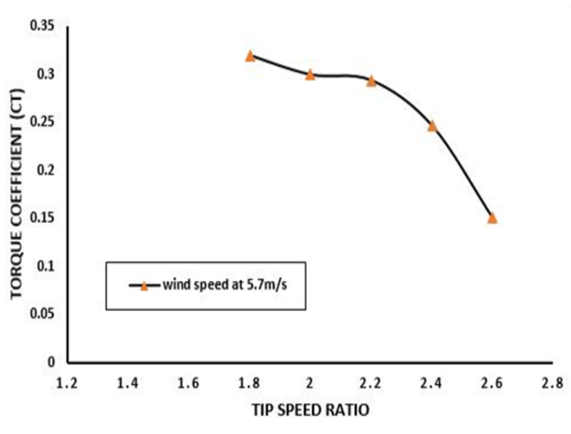

Figure.8. Torque coefficient vs Tip speed ratio

4.2 Power Performance

Power is the product of torque and omega. Initially, the power found to be low but as tip speed ratio increases the power also increases while after an optimum TSR i.e 2-2.4 power starts to reduce because of torque reduced in turbine. When turbine blades move in a disk form so it can be considered that the reduced torque reduces the power as shown in figure 9. It can say that the point where torque and rpm intersects or found maximum at certain optimum point so there the power of turbine will be maximum.

To find power coefficient of the turbine it was necessary to obtain power but the result was similar to power. It is noted that at low tip speed ratio the turbine rotates slowly so maximum wind passes across the blades without more power transfer. In its comparison as the tip speed ratio increases blades starts to move fast so the fast moving blades appears similar to solid disc due to this the power coefficient of turbine decreases as shown in figure 10. Here we can say that the power output is directly affected by tip speed ratio so it is difficult task to evaluate its optimal value. It is observed that low TSR ranges 2-2.6 are preferable for better power performance of small scale vertical axis wind turbine.

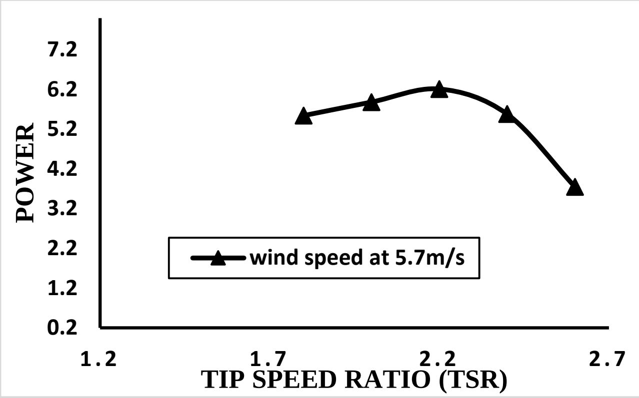

Figure 9. Power vs Tip speed ratio

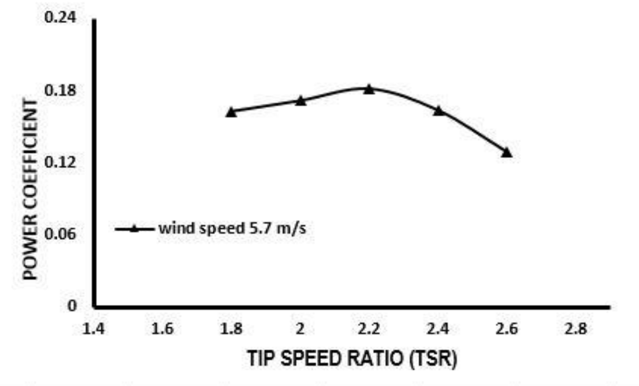

Figure.10. Power coefficient vs Tip speed ratio

5. Conclusion

This paper presents a broad analysis of the design and performance of turbine. During this research the torque and power performance of H Darrius vertical axis wind turbine is examined in open atmosphere. Where initially its prototype of turbine was made from CAD modelling and then their design was fabricated. While testing turbine, the spring balance is used to measure torque of the turbine. Whereas the Ct and Cp values were found numerically and graph were made to understand turbine behavior and also analyzed the effect of TSR. The effect of TSR for torque and power coefficient is listed below:

The torque performance is high at low tip speed ratio (1.8-2) as the TSR increases the Ct of the turbine reduces in open atmosphere.

Similarly, the power and power coefficient of turbine recorded high at low tip speed ratio but after an optimum point (2-2.2) as the TSR increases the performance of turbine also decreases.

It is observed that low TSR ranges 2-2.6 is preferable for better power performance of small scale vertical axis wind turbine.

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