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Comparative Study of Disc and Blade Type Wind Turbine

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Abstract - Disc Wind Turbine is a new developed design of a wind turbine which does not use traditional aerofoil section blades. Developing a turbine that uses three discs mounted along the periphery of the central hub in specific geometry and convert the kinetic energy of the wind, much more efficiently into rotational mechanical energy which could further be converted into electrical power. The working principle of this method along with the experiment to obtained by directly comparing our design with traditional wind turbine. Also we have done CFD flow analysis on different angle of disc.

Key Words: Wind power, Disc wind turbine, Drag force, Electricity, Angle of disc.

1.INTRODUCTION

1.1 History

According to the Encyclopedia of alternative energy, wind energy: in the beginning of the 20th century, great plains were commonly using windmills in order to pump water and generate electricity as well. However new technologies of using wind energy started to spread all over the world. In the 11th century, the Middle East used in an extensive manner windmills for food production, crusaders and returning merchants carried this idea back to Europe. On the other hand, the Dutch refined improved windmill and used it for draining lakes and marshes in the Rhine River Delta. Later on, in the 19th century the new world started using the windmills technology in order to pump water for farms and ranches and afterword to produce electricity for home use and industries.

The industrial revolution led to a decline in the use of windmills first in Europe than in America. The European water pumping windmills were replaced by steam engines, and in 1930 United States brought inexpensive electric power to most rural areas. Nevertheless, industrialization helped in developing windmills meant to generate electricity. Usually called wind turbines, these machines appeared in the first place in Denmark in the 1890s. Moreover, in the 1940s the largest wind turbine of the time began operating on the Vermont hilltop. This turbine was rated at 1.25 megawatts in winds of about 30 Mph; it produced electricity to the local utility network for several months during World War II. The use of wind turbine has always been related to fossil fuel price, where the fuel prices after World War II went down that's why the interest in wind turbine decreased. Nonetheless, when the price of oil increased in the 1970s, the demand for wind turbine generators increased as well.

1.2 Type of Wind Turbine

Wind turbines are classified into two general types:

i) Horizontal axis wind turbine (HAWT):

A horizontal axis turbine has its blades rotating on an axis parallel to the ground.

ii) Vertical axis wind turbine (VAWT):

A vertical axis turbine has its blades rotating on an axis perpendicular to the ground.

Wind power is one of the perennial sources of energy along with being available during day time as well as at night time almost throughout the year which could be harnessed from most of the parts of the planet. But modern-day wind turbines could convert only up to around 45 percent of the total energy content in the wind. Wind energy is being used since a long time for generating useful work like cruising a ship through ocean to grinding grains in mills powered by wind to modern electrical energy generation by harnessing this immense wind power.

A conventional turbine uses an aerodynamic lift and reaction force generated while wind moves past each blade. These turbines generally have three blades with relatively smaller width compared to the length equally spaced from each other and have a large amount of unoccupied space between these blades. This is explainable since these conventional turbines generate power by the means of flow concept, which means that greater the velocity of wind flowing over these blades the greater will be the power generated, and hence if three blades, with relatively small width are designed then it would create less overall drag force and the wind could easily move with same speed over the blades. If the number of blades is increased to around six or ten, then there would be a large drag force offered to the flowing wind and the velocity of the wind flowing past each blade would decrease and hence would develop less power along with increase in cost of additional blades and weight constraint.

Due to this a traditional turbine has small width of blades, in order to prohibit the decrease in the wind speed due to drag effect and letting most of the upcoming stream of wind to be passed over the blades and develop the motive power.

1.3 Working Principle

Our design is inspired from one of the oldest sources of wind energy harvesting technique which is the sail of a ship along with the shape of an umbrella. Sail ships are propelled by the huge drag force experienced by the massive sails which are kept at a certain angle with respect to direction of wind flow in order to steer the ship in the desired direction in the down-stream of a wind current. Our turbine works in a similar way but allows the sails to rotate in order to obtain power, we are referring this technique as wind capture, and this will be discussed shortly. The another technology that we are using is the reactive force thrust generation, in which the wind when moves past the blades which are moving in relatively lesser speed than that of the wind impart some tangential reaction force while leaving the disc edge thus providing an extra moment towards the centre. Yet another technology, which in fact is a controlling technology that we are using, is the adaptable blade technology in which the angle of these blades relative to the central shaft will be automatically changed depending up on the wind conditions. All these three key techniques are further briefed below.

1.4 Components of Wind Turbine

1.4.1 Disc blades

Lifts and rotates when wind is blown over them, causing the rotor to spin. Most turbines have either two or three blades.

1.4.2 Tower

Made from tubular steel, concrete, or steel lattice. Supports the structure of the turbine. Because wind speed increases with height, taller towers enable turbines to capture more energy and gene rate more electricity.

1.4.3 Nacelle

Sits atop the tower and contains the gear box, low- and high-speed shafts, generator, controller, and brake. Some nacelles are large enough for a helicopter to land on.

1.4.4 Shaft

Shaft is used for the drives the generator.

Low-speed shaft: Turns the low-speed shaft at about 30-60 rpm.

1.4.5 Rotor

The disc and the hub together are called the rotor.

1.4.6 Bearing

A bearing is a device that is used to enable rotational or linear movement, while reducing friction and handling stress.

1.4.7 Hub

The disc is directly bolted to the hub and are unable to pitch, which leads to aerodynamic stall above certain wind speeds.

1.4.8 Generator

Produces 60-cycle AC electricity; it is usually an off-the-shelf induction generator.

1.5 Wind Capture Technique

As mentioned earlier our design is largely inspired from sail of the ship. A sail of the ship is used to provide a motive power for the ship to move. When the sail is tilted along the direction of wind one side of the sail faces the wind directly on its frontal area than the other sides of the sail, due to this high pressure is created on the windward side than other sail sides and the sail gets a pushing force from high pressure side. In a sail ship due to the angle of the sail, some wind power is utilized in moving the ship forward and some power in moving the ship sidewise since the high pressure side generates almost a perpendicular force to the wind velocity, but a ship utilizes a stabilizers and long fins submerged under water which minimizes this lateral movement and only allows forward thrust. Our disc will perform in almost a similar manner with the change being, our design would utilize the lateral force generated when wind is imparted on the discs.

Figure 1.1 Sailboat

Due to the disc design, wind will impose a huge drag force in the direction of the wind; again, as these discs are angled relative to the central shaft, this drag force now could be resolved into two components one tangential component and other simple pushing force. This tangential component acting at the end of the connecting rod where the disc will be mounted is the most important factor as it would provide a turning moment necessary to rotate the turbine and hence the generator connected to the central shaft and produce electrical energy.

1.6 Reactive Force Technique

When the wind blows over the disc most of the kinetic energy of the wind is used to create the drag force when it is imparted on the discs, but still it contains enough energy to flow past the discs. These discs are angled, due to which one side of the disc is higher than the other side. The wind flows past these discs from the side which is slightly lower than the other side. Here the wind speed is still slightly higher than the tip velocity of the rotating disc and hence while leaving the disc it imparts some reactive force on the tip of the disc in the direction of motion of the disc tip. This force contributes to the total torque generated at the center and this torque can be calculated as the force times the distance between connecting rod disc attachments to the center of the shaft.

1.7 Advantages

- Utilization of maximum kinetic energy of wind.
- More electricity output.
- Cost of entire wind mill is low.

1.8 Disadvantages

- More friction force generates.

1.9 Limitation

- It does not run at very low speed of wind.

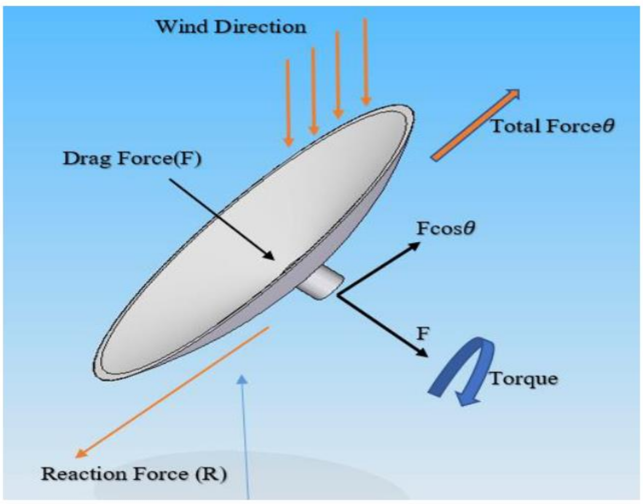


Figure 1.2 Reactive Force Technique

Chapter 2 Literature Review

Austen Thurmond, Roberto Villazana, and Victoria Nguyen, A Tunisian start-up Saphon Energy has developed a similar bladeless single disc designed turbine which converts wind energy into mechanical energy and then into hydraulic energy by pistons inside the hub. The hydraulic energy could be converted into usable electrical energy by a hydraulic motor. As the design uses single disc, it has a tendency to wobble and the structure starts shaking in high winds. [1]

Peter Vidmar and Marco Perkovic, the research explained in this paper was carried out to investigate the efficiency of different steering systemson sailing yachts. The steering system of a sail yacht mostly includes a simple steering system and a hydrodynamic shaped single rudder or multiple rudders, depending on boat characteristics. One of the basic design guidelines for fast sailing yachts is to reduce wetted surface to minimum allowed by the dynamic stability and maintaining the sailing performances. Deficiencies of different steering systems are discussed and their influences on total drag and yacht manoeuvrability in different sailing directions is analysed. The purpose of the research was to demonstrate that the use of the bended rudder can reduce the leeway angle, the upwind sailing angle and increase the velocity made good to windward. [2]

M. Jaivigneshand B. VijayaRamnath, this paper mainly deals with analysis of problems involved in an agricultural instrument called Disc Plough. After thorough analysis of the machine and from various observations we came to know that the weight of the disc plough. Hence the main objective of our paper is to change the design as well as the material of Disc Plough. [3]

Jorge Alexander Alarcón, Jairo Eduardo Hortúa and Andrea López G, this paper presents the development of a solar parabolic dish collector prototype for rural areas with high solar resource availability in Colombia, which have no access to electricity service or budget resources to purchase a stove (electric or gas). The solar collector prototype proposes a solution to solve these kinds of issues and use sunlight to work it. Through a polished stainless-steel parabolic dish, solar radiation is concentrated into a specific area called focus, where thermal energy is generated and is used for cooking or fulfilling a necessity without high investment and helping the environment. To finish, it describes the decisive stages of the prototype implementation, which provides the solar resource analyzed in Colombia, the theoretical analysis, the structural design, the study, and manufacturing materials. [4]

Peter J. Schubel and Richard J. Crossley, a detailed review of the current state-of-art for wind turbine blade design is presented, including theoretical maximum efficiency, propulsion, practical efficiency, HAWT blade design, and blade loads. The review provides a complete picture of wind turbine blade design and shows the dominance of modern turbines almost exclusive use of horizontal axis rotors. The aerodynamic design principles for a modern wind turbine blade are detailed, including blade plan shape/quantity, aerofoil selection and optimal attack angles. A detailed review of design loads on wind turbine blades is offered, describing aerodynamic, gravitational, centrifugal, gyroscopic and operational conditions. [5]

Muhammad Uzair, Timothy Anderson1, Roy Nates, and Etienne Jouin, in order to investigate the flow behaviour, a three-dimensional computational fluid dynamics (CFD) model was used to predict the steady-state flow around the parabolic solar dish at different operating conditions. The CFD model was subsequently validated with experimental data collected from wind tunnel testing for the dish at different pitch angles and with varying wind speeds. The results support the assertion that the flow characteristics near the cavity receiver aperture depend strongly on the orientation of the dish structure and this needs to be considered when analysing the performance of parabolic dish systems. [6]

TroelsFriis Pedersen, Uwe Schmidt Paulsen, the paper proposes a classification procedure for cup-anemometers based on similar principles as for power converters. A range of operational parameters are established within which the response of the cup-anemometer is evaluated. The characteristics of real cup-anemometers are fitted to a realistic 3D cup-anemometer model. Afterwards, the model is used to calculate the response under the range of operational conditions which are set up for the classification. Responses are compared to the normal linear calibration relationship, derived from wind tunnel calibrations. Results of the 3D cup-anemometer model are presented and the influence of over speeding, angular response and friction in bearings are derived. The results are put into a classification scheme. [7]

Dr. Anass Bentamy, Dr. Sedki Samadi, the objective of this paper is to review the design of the main shaft of a small wind turbine in terms of its dimensions, primarily the diameter, and the type of material used to produce it. These are the design factors that will affect the execution process of the main shaft. This will allow for improving the wind turbine's productivity and optimizing its costs. [8]

Mr. Monir Chandrala, Prof. Abhishek Choubey, Prof. Bharat Gupta, in this paper a horizontal axis wind turbine blade with NACA 4420 is designed and analysed for different blade angle and wind speed. The CFD analysis is carried out using ANSYS CFX software. The velocity distribution at various blade angles is carried out in this paper. [9]

Paul Wade, from this research paper we follow the design of parabolic disc antenna and find out focal length for it. [10]

2.1 Problem Definition

The convectional design of the wind turbine is less efficient, consuming great amount of space and providing low output electrical energy. The cost of the entire wind farm project is very high, and this could be the main reason for reluctance to most of the wind energy projects. The manufacturing facilities required for construction of massive blades of turbine are not cost effective to build. The transportation cost involved in carrying huge and heavy machinery is high. Along with this the set-up measures required to assemble the convectional wind turbine on site are quite cumber-some and involves a high amount of risk. Convectional wind turbines are low torque for the given wind flow. These turbines are effective only when wind speeds are quite high, they are inefficient in low wind conditions.

Chapter 3 Experimental Setup

3.1 Assumption for Experiment

- Constant wind speed is 5 m/s.
- Rotor diameter is approx. 1 m.
- The distance between table fan and fabricated model is 2 m .
- Experiment was performed in the room.

3.2 Creo modeling of Disc and Blade Type Wind Turbine

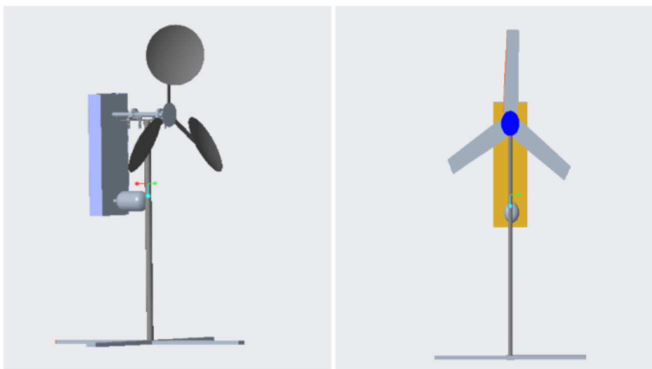


Figure 3.1 Creo modeling of Disc and Blade Type Wind Turbine

3.3 Fabricated Model of Disc and Blade Type Wind Turbine

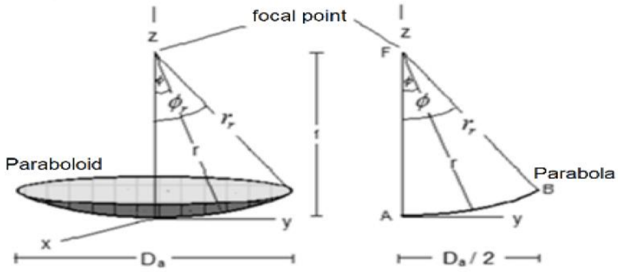
Figure 3.2 Fabricated Model Of Disk And Blade Type Wind Turbine

3.4 Design Calculation of Parabolic Disc

The parabolic disc is chosen for blade modelling as shown in figure. The modelling is done with Creo 4.0. The blade is modelled for the specification given below.

Diameter of aperture (Da) = 30 cm = 0.3m

Depth of parabola curve (dp) = 3 cm = 0.03m



From above diagram assumes prototype dimensions for parabola disc.

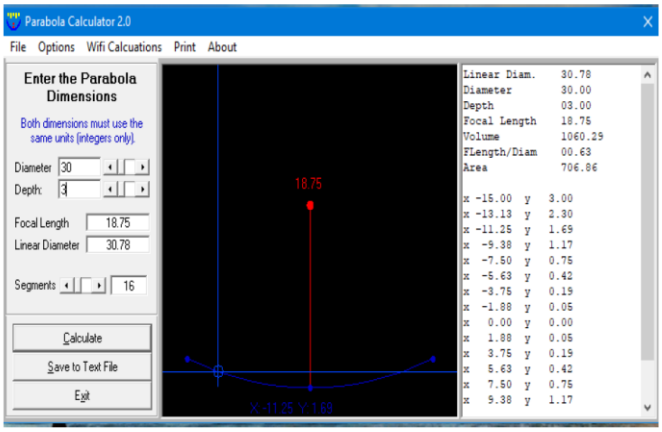


Figure 3.3 Design Of Parabolic Disc

By analysis of parabola curve in parabola calculator 2.0 software as above data we get focus length.

Focus length (F) = 18.75 cm = 0.1875 m

Area (A) = 706.86 $cm2$ =0.0706 $m2$

f = $D216d$ = 30216∗.3

f = 18.75 cm = 0.1875 m

Parabola Equation

y =$ax2$, a = 1 4f=0.013

y =0.013$x2$ fD =0.625

3.5 Design Calculation of Shaft

1)Torque

T = $(P\times60)/(2\times\pi\times N)$

= (1× 〖10〗 ^3×60)/(2×π×200)

T = 47.74×103 N·mm

2) Tension at both side

T = $(T1- T2)$ R

Where R= Radius of sprocket = 140 mm

Assume μ=0.3

θ=180

$T1T2$=2.566 $T1$=2.566 $T2$

47.74×103= (2.566 $T2$ −$T2$) 140

$T2$=304.85 N

$T1$=782.25 N

3) Total vertical load acting on shaft

$WVB= T1+T2+Wb$

Where Wb= Weight of blade = 3 kg

= 304.85 + 782.253 + 29.43

= 1116.53 N

4) Tangential load acting vertically upward on sprocket

$Ft= TR$ = 47.74×103140 = 341 N

5) Total vertical load acting on shaft at B $WvB=-ft+Ws$=−341+3.924

= -337.07 N

6) Total vertical load on shaft

$Wv=wvA+wvB$

=1116.53−337.07

=779.46 N

7) Bending moment acting on shaft Taking moment

about D

Rc×200=(1116.53×1000)+(337.07×50)

Rc=5666.91 N

For the equilibrium of the shaft Rc+337.07=RD+1116.53 RD=4887.45 N

Bending moment at C

Mc = 1116.53 × 50

= 55.82×103 N·mm

Bending moment at D

MD = 337.07×50

= 16.85×103 N·mm

Maximum bending moment

M = Mc= 55.82 ×103 $N \cdot mm$

8) Equivalent twisting moment

$Te= \sqrt{(km\times M)2+(kt\times T)2}$

=√(2×55.82×103)2+(1.5×47.74×103)2
Te=132.63×103Nmm

9)Diameter of shaft

$Te=\pi16\times\tau\times D3$

132.63×103=π16×(63)×103

$If\ \ \tau=63N/m2$

$\boldsymbol{D=22.050\ mm}$

3.6 Calculation for wind turbine

3.6.1 Power

$P=\pi8\times\rho\times D2\times v3$

$D2$=400×8π×1.225×1000

D=0.96m ≅1m

3.6.2 Drag Force

$Fd=Cd*A*\rho*V22$

Fd=0.998 ≈1 ,N

3.6.3 Axial thrust (Thrust force)

$Fx=\pi9\times\rho\times D2\times v2$

$Fx=\pi$9×1.225×12×52

Fx=10.69 Nm

3.7 Bill of Material

Table 3.1 Bill of Material

SR.NO.	List	Material	Qty.	Cost(rs)
1	Disc blade	Steel	3	300/-
2	Shaft	M.S	1	250/-
3	Bearing	-	2	440/-
4	Chain Drive	-	1	300/-
5	Tower	M.S	1	250/-
6	Generator	-	1	1000/-

7	Hub Plate	M.S	1	50/-
8	Nut and Bolt	M.S	12	150/-
9	Outer Casing	G.I Sheet	1	450/-
10	Base (C-Channel)	M.S.	1	350/-
Total Cost				**3540/-**

Chapter 4 Result and analysis

4.1 Experimental Readings

After designing the components for testing power output for wind turbine to be tested, we created workable model a small-scale model of disc turbine was built and along with this a model of traditional three bladed wind turbine of similar dimensions was tested. This parabolic disc made up of steel. The test set up was in the room using a table fan. We put the disc at different angle of attack with a same velocity by using table fan. We tested the power output of the turbine blade and disc.

Two experiments have been conducted; the procedure of calculating the power is counting the DC voltage & DC current that can be measure by multimeter and we are also changing the blade angle like 0°,15°,30°,45° and 60°. The power gained can be calculated using the below equation.

P=V*I

4.2 Experiment: 1

We have performed this experiment in close room where 1 side is open to Air.

Table 4.1 Experiment 1 for Disc

Sr no.	Angle of disc	Wind speed(m/s)	Voltage(V)	Current(I)	Power(Watt)
1	0	5	0	0	0
2	15	5	2.05	1.475	3.024
3	30	5	1.025	0.95	0.974
4	45	5	0.58	0.58	0.405
5	60	5	0.84	0.84	0.928

Table 4.2 Experiment 1 for Blade

Sr no.	Angle of blade	Wind Speed (m/s)	Voltage (I)	Current (I)	Power(Watt)
1	0	5	0	0	0
2	15	5	0.55	0.3	0.165
3	30	5	0.86	0.475	0.409
4	45	5	0.525	0.4	0.21
5	60	5	0.43	0.2	0.081

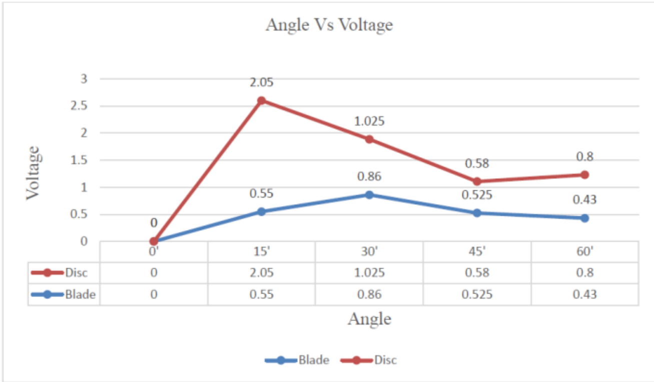


Figure 4.1 Graphical representation of Blade angle vs Output voltage

From above graph we get maximum voltage at angle 15 for disc and at angle 30 for Blade.

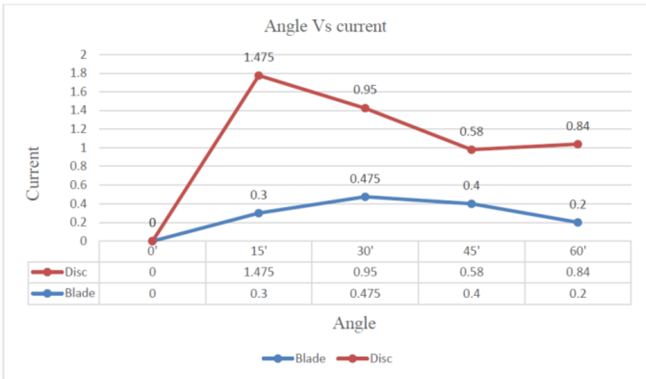


Figure 4.2 Graphical representation of Blade angle vs Current

Form above graph we get maximum current at angle 15 for disc and at angle 30 for blade.

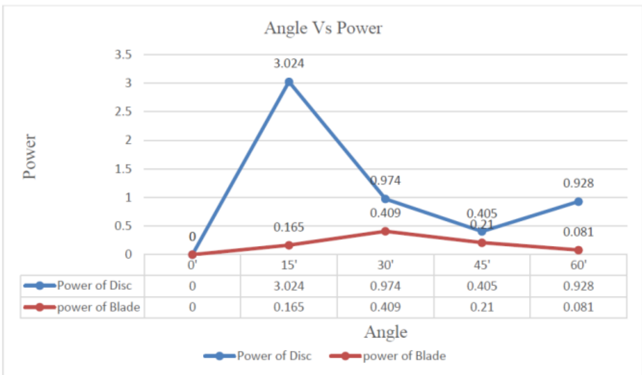


Figure 4.3 Graphical representation of Blade angle vs Output Power

From above graph we get maximum power for disc output at angle 15 and power is gradually decrease up to angle 45 then further increase in power till angle 60. while for blade power is gradually increase up to angle 30 then it gradually decreases.

4.3 Experiment: 2

We have performed this experiment in completely close room.

Table 4.3 Experiment 2 for Disc

Sr no.	Angle of disc	Wind speed(m/s)	Voltage(v)	Current (I)	Power (watt)
1	0	5	0	0	0
2	15	5	1.2	0.30	0.36
3	30	5	0.6	0.48	0.288
4	45	5	0.385	0.259	0.0997
5	60	5	0.240	0.048	0.0115

Table 4.4 Experiment 2 for Blade

Sr no.	Angle of blade	Wind speed(m/s)	Voltage(V)	Current (I)	Power (Watt)
1	0	5	0	0	0
2	15	5	0.3	0.18	0.054
3	30	5	0.45	0.28	0.126
4	45	5	0.18	0.13	0.0234
5	60	5	0.06	0.01	0.0006

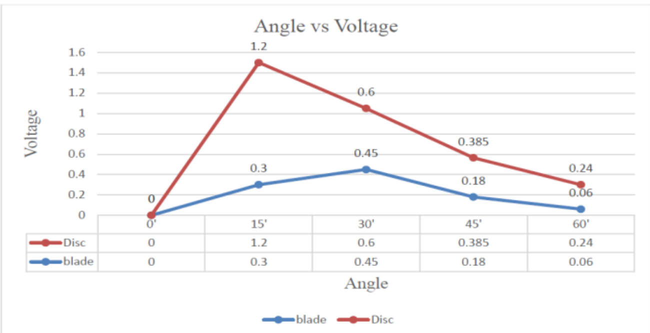


Figure 4.4 Graphical representation of Blade angle vs Output Voltage

From above graph we get gradually increase voltage up to angle 15 for disc after voltage decrease gradually. For Blade, voltage is gradually increase up to angle 30 then decrease gradually.

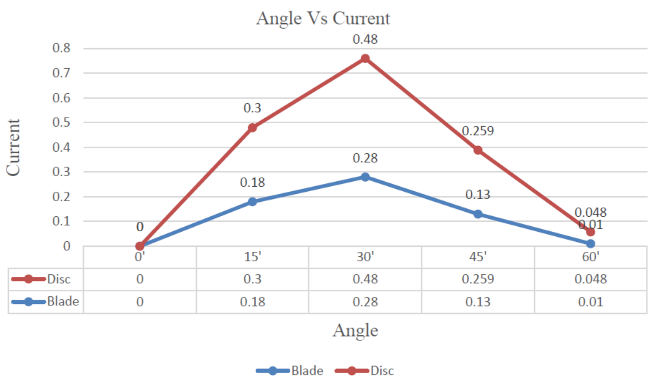


Figure 4.5 Graphical representation of Blade angle vs Current

From above graph, we get gradually increase current up to angle 30 then it reduces gradually.

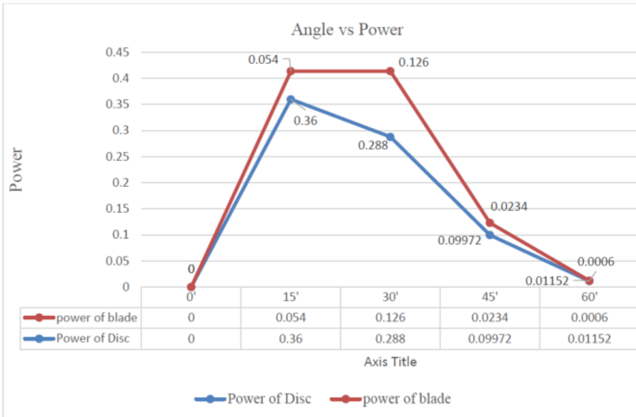


Figure 4.6 Graphical representation of Blade angle vs Output Power

From the above graph we get gradually increase power output up to angle 15 then decrease gradually. For blade power is gradually increase up to an angle 30 than decrease gradually.

4.4 CFD Flow analysis

The parabolic disc is created in Creo 4.0 software and the CFD analysis is performed in ANSYS 14.0 CFX. A smart fine mesh is created for the flow area. We are taking Fluid type domain and working fluid as air at 25 °C. Inlet velocity for the experiments and simulations is 5 m/sec and turbulence viscosity ratio are 5%. A fully subsonic flow solution was used in ANSYS 14.0 CFX. A simple solver was utilized, and the operating pressure was set to 1 atm. Calculation was done for the subsonic region. The CFD analysis is carried out using ANSYS14.0 CFX software. The velocity distribution at various blade angles is shown in figure.

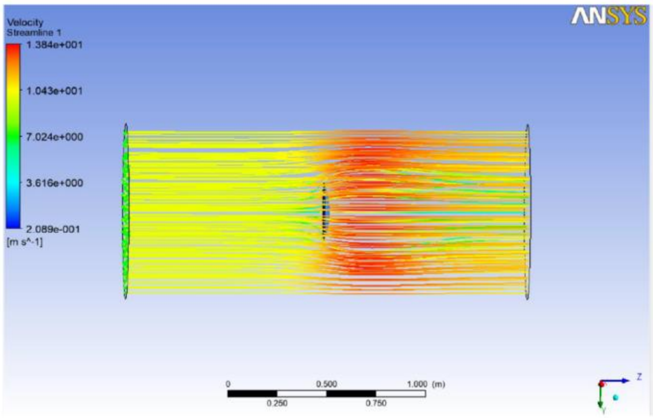


Figure 4.7 Velocity streamline of disc at 0°

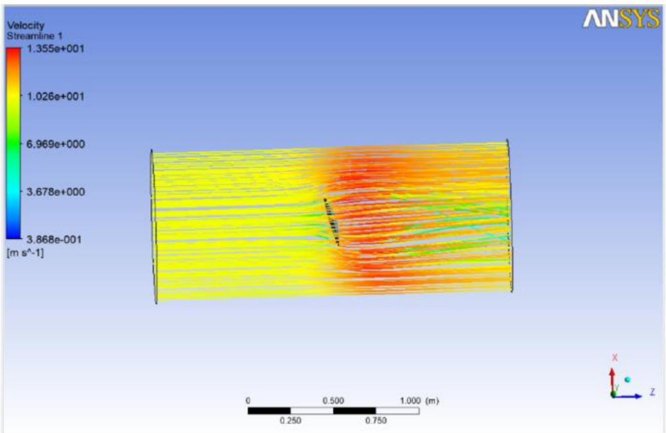


Figure 4.8 Velocity streamline of disc at 15°

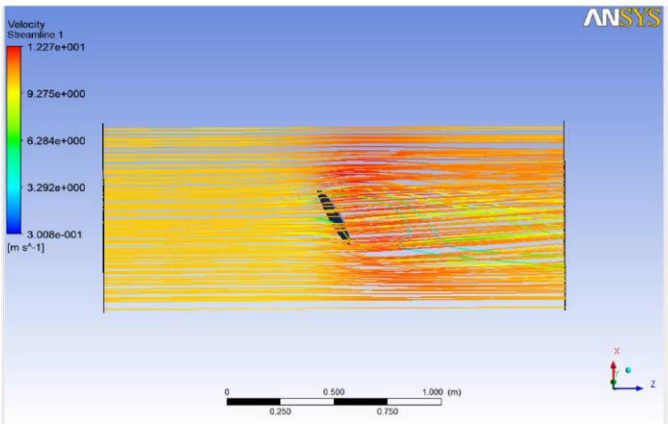


Figure 4.9 Velocity streamline of disc at 30°

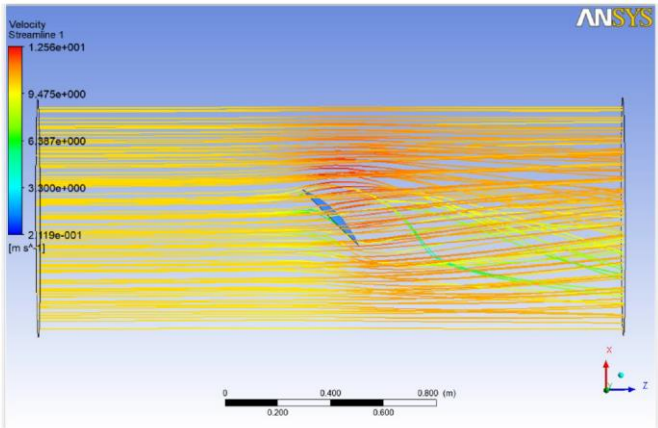


Figure 4.10 Velocity streamline of disc at 45°

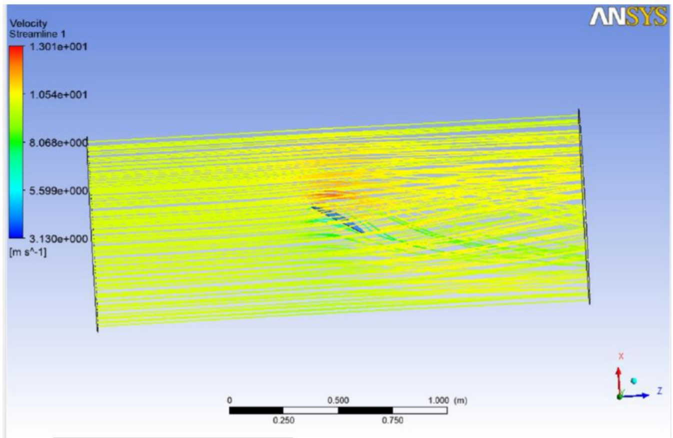


Figure 4.11 Velocity streamline of disc at 60°

Chapter 5 Conclusion

After the CFD analysis we have observed the flow of air on the disc turbine at different angle. The experiment carried out under similar wind conditions displayed Disc Turbine is capable to produce voltage more than a traditionally made turbine. We got maximum power output at angle 15° to 30°compare to conventional blade.

Chapter 6 Future Scope

In future everything should have more efficiency and having low cost, and for that different technologies and modifications are done in new and existing thing.

- Mechanism provide for automatic changing the angle of attack of disc wind turbine.
- Advanced control methods (individual pitch).

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