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Experimental Investigation and Fabrication of Self Closing Savonius Wind Turbine

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Abstract: The objective of the project is to design a new blade mechanism to reduce the blade damage caused due to high wind speeds during operation of the wind turbine. There has been a very sturdy increase in harnessing wind energy all over the world. In today's world there are many types of turbines which are used for harnessing the wind energy. One such type is the savonius wind turbine which we have concentrated on in this project. This is a vertical axis wind turbine (VAWT). There are two type of mechanisms used in a VAWT to convert the wind energy to mechanical energy.They are lift type and the drag type. Savonius turbine is a drag type wind turbine which uses the drag force created by the wind on the turbine blades to rotate the blades over the axis of the turbine. Due to high wind speeds during various climatic conditions the blades of the turbines are damaged and hence reduces the efficiency of the blades. They are also expensive to repair. Hence we have come up with a new speed limiting mechanism to safe guard the blades from getting damaged. Research in this area will contribute in overcoming the disadvantages of the technology and move towards a more viable technology for mass use. They are very compact against the horizontal wind turbines. They can coexist with the existing infrastructure without high cost.

I. INTRODUCTION

Wind Energy has become significant part of the worlds overall power grid. Having a lot of advantages over the traditional non renewable source of energy.

Technology to harness this form of energy has been there for a very long time. In the earlier days it was in the form of windmills which converts the wind energy to mechanical work which are used to pump water etc. whereas now the technology has evolved and we are able convert the mechanical energy and store it as electrical energy in batteries and use it for various applications by the use of wind turbines .

Now this technology has the capability of contributing to the country's power requirement. There are two kinds of wind turbines based on design, they are horizontal axis wind turbine (HAWT) and vertical axis wind turbine (VAWT).The advantages of vertical axis turbine are that they are easy to design and construct, lower cost to build, they don't need a rotor yaw mechanism as they can operate in any direction of the wind and ecosystem damage is less.

The disadvantage of this type of wind turbine is that its efficiency is less, high fluctuations in power production, lower blade speeds and lower energy yield.

Due to population growth there has been a steep increase in the energy needs in the world. Since in the advancement of science the average power consumption per house has also been increased due to the increase in electronic goods. Due to all this all the countries are looking for a renewable energy source to balance the needs and the non renewable energy source is depleting in a very fast pace and environment damage it causes has been significant. To counter all this there is a need to reduce our dependence on nonrenewable source of energy This project determines the optimal size for a wind turbine to supplement power requirement to light at least a bulb.

Classification Of Wind Turbine based on the axis of rotation :

A. Horizontal Axis Wind Turbine

Horizontal-Axis Wind Turbines (HAWTs) the blades are attached perpendicular to the axis of rotation on the hub. The rotation axis is horizontal to the ground hence it is know as HAWT. The blades rotate due to the lift generated by the winds due to the aero foil shape of the blades. The blades are connected to a hub which is connect to the shaft which is the rotating axis this is connected to the generator which is present at the back of the blades inside a housing called nacelle. It has a YAW mechanism to move the whole top assembly to the direction of the wind for the better efficiency. These are placed very high ion a tower to capture the high velocity winds for the best efficiency. These types of turbines are very expensive.

B. *Vertical-Axis Wind Turbines (VAWTs)*

Vertical Axis Winds Turbine the blades are attached to the rotating shaft which is perpendicular to the ground. There are two types of VAWT based on the working mechanism. One is the drag type and another is the lift type. Drag type uses the wind force that acts on the blades which stops the direction of the force hence converting the kinetic energy of the wind to rotation of the blades that is mechanical energy. The shaft is connected to the generator and hence produces electrical energy. The lift type works like the HAWT uses an aero foil shape to produce lift to rotate the shaft. Thus producing electrical energy.

II. BACKGROUND

A. *Wind Turbine*

A wind turbine is a device that is used to harness the wind energy, they are also know as wind convertor for the same reason. These devices converts the kinetic energy of the wind to electrical energy and store it in power backup units like batteries for further use. The smallest turbines are used for charging batteries for auxiliary power for boats or caravans or to power traffic warning signs. Whereas the larger turbines are for domestic power supply.

1) *Types of Wind Turbine:* Wind turbines are broadly classified into two types. They are Horizontal Axis Wind Turbine (HAWT) and Vertical Axis Wind Turbines (VAWT). Horizontal-axis wind turbines are widely used compared to the vertical axis wind turbine. This type of wind turbine is characterized by a higher aerodynamic yield than the vertical one. The generally have three blades that are aerodynamically shaped like airplane wings. In this case, the lift is used for generating a driving torque causing rotation. The number of blades used for electric power generation varies between one and three; the three blades has a better implementation over the other two taking all factors into account. This type of wind turbine has more advantages and is widely used over those with vertical. Moreover, they are more expensive and less exposed to mechanical stresses, and the position of the receiver at several tens of meters of the ground favors the efficiency. Vertical-axis wind turbines (or VAWTs) have the main rotor shaft arranged vertically with respect to the ground. The main advantage of this arrangement is that the turbine does not need to be pointed into the wind to be effective, which is an advantage on a site where the wind direction is highly variable. It is also an advantage when the turbine is integrated into a building as it is cheap and can perform well in high rise buildings. Also, the generator and gearbox is be placed near the ground, improving its accessibility for maintenance. However, this design produces less power then the HAWT.
2) *Types of Horizontal Axis Wind Turbines:* They are classified based on the number of blades the turbine possesses. Based on the number of blade the horizontal axis wind turbine are classified into three types. They are Single blade wind HAWT, Two blade HAWT and Three blade HAWT. Single blade HAWT are used to reduces the cost and weight of the turbine. These are rarely used due the need of counter weights on the other side of the blade for stability.

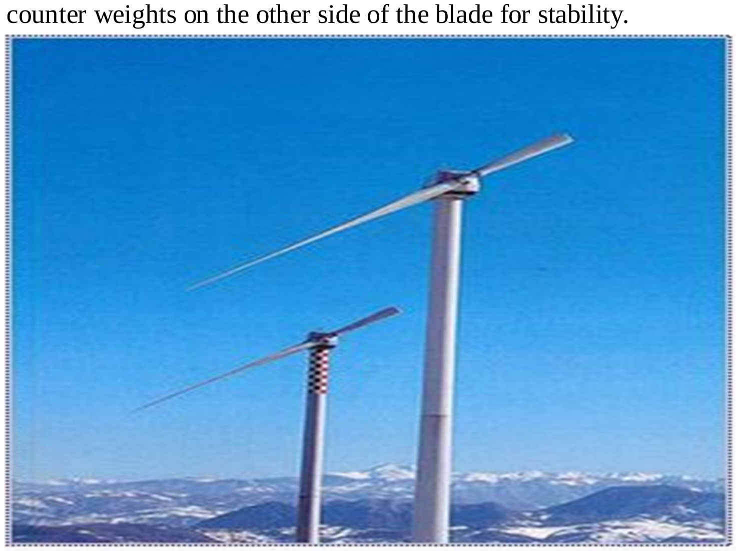

Fig 2.1: Single blade wind turbine

Two blade HAWT have two blades unlike the single blade HAWT. It needs more complex design as it has to sustain wind shocks and is also less stable.

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Fig 2.2: Two blade wind turbine

Three blade HAWT concept are being used by modern wind turbines. Because this structure has high strength to withstand heavy wind storms. Less effect due to tower shadow. Produces high output.

Fig 2.3: Three blade wind turbine

Veritcal Axis Wind Turbine are classified based on the design of the turbines. There are many VAWT like Darrieus wind turbines, H-Darrieus wind turbines and Savonius wind turbines

Darrieus turbines are vertical turbines whose blades are aero foils that use lift force to turn the rotor and generate electricity. They were designed and first fabricated by the French aeronautical engineer Georges Jean Marie Darrieus in the 1920s. Their working principle is quite different from that of horizontal axis turbines, even though they both rely on the forces of lift. After the turbine starts rotating, the motion of its blades through the air creates an apparent wind that is relative to the rotating blades.

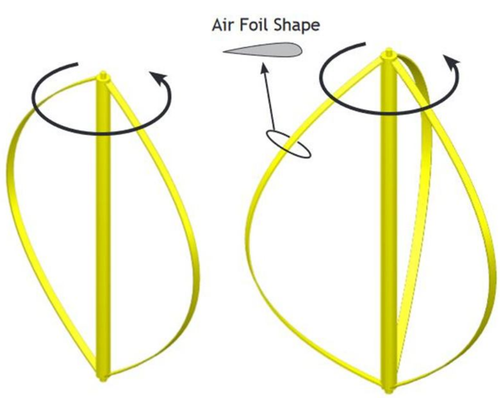

Fig 2.4: Darrieus wind turbine

The H-Darrieus rotor is also known as the Giromill rotor . It is a more efficient version of the darrieus rotor. The curved blades are replace by the straight blades which are easy to manufacture as well as they offer more efficiency than the darrieus rotor. This makes it more attractive than the darrieus rotor both economically as well as technically. There are also pitch variable version of the blades which offers better efficiency as well as give it the self-starting capability.

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Fig 2.5: H-Darrieus wind turbine

Savonius wind turbine was invented by the Finnish engineer Sigurd Savonius in 1922. It is the most basic design of a wind turbine. It has a s shape blade when viewed form top cross section. It is a two blade configuration with an extremely easy design compared to the other types of turbines. Its working principle is also very easy where the rotor rotates using the drag force created by the wind while passing through it.

Fig 2.6: Savonius wind turbine

B. BETZ'S LAW

Betz law is named after German physicist Albert Betz which states that the maximum theoretical efficiency any wind tubine can attain. It states that the maximum kinetic energy from the wind flow that can be extracted by any turbine is 16/27 (59.3%) and can't exceed this value. Thus according to this law, no turbine can extract all the speed out of the flowing wind, and the wind will always have a flow after passing through the turbine.

Below plot that shows the power coefficient of a turbine Cp (the ratio of the extracted power to the available power) vs. the ratio of the speed of the wind before and after passing through the turbine:

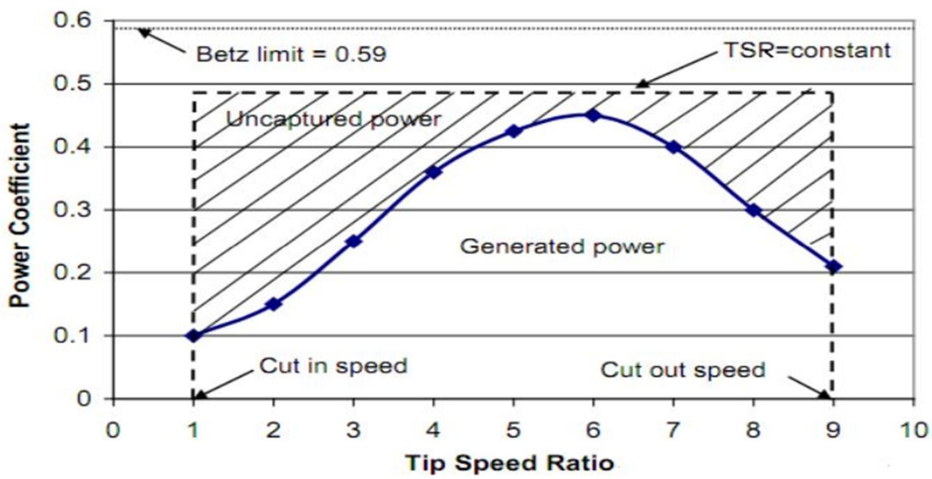


Fig 2.7: Performance coefficient VS Speed ratio

C. Power Curve

The power curve is a plot that describes the performance of a wind turbine at different wind speeds. It shows the electrical energy power output vs the wind speed and gives an idea about the minimum and maximum wind speeds for a wind turbine.

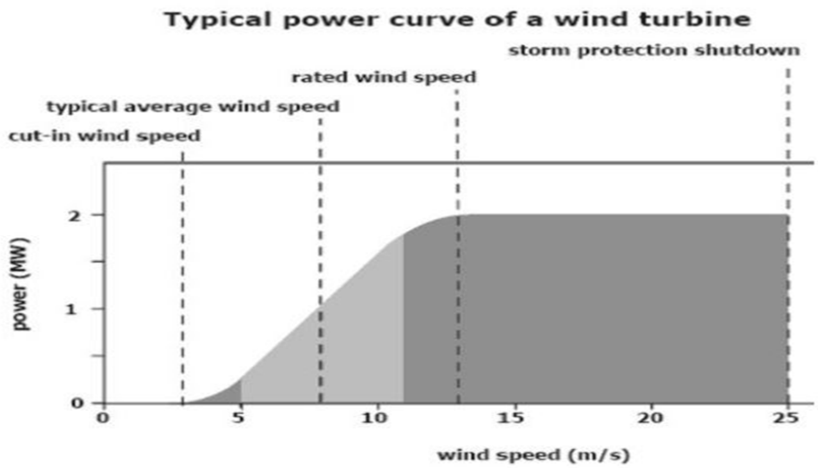


Fig 2.8: Power Vs Wind Speed

D. Working Principle

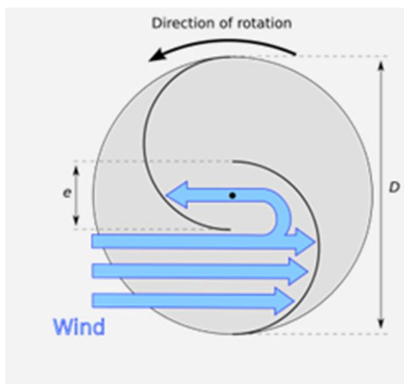


Fig 2.9: Wind flow

Savonius wind turbine can produce electricity in any wind direction. When the wind flows through the turbine blades it creates a difference in pressure due to the wind flow. This difference in pressure leads to the rotation of the blades. Drag forces act on the surfaces of the blades making it rotates over the shaft.

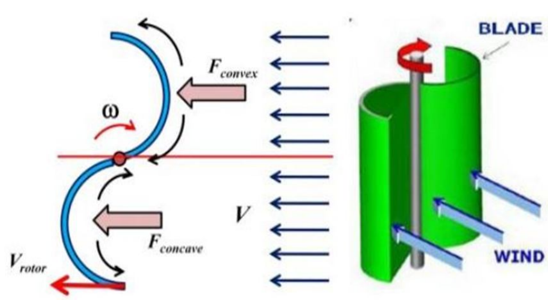


Fig 2.10: Force acting on turbine blades

The air is trapped in the concave part and pushes the turbine. The flow that hits the convex part does produce a drag that is lower than the one on the concave part. It is the differential of the drag force that causes this turbine to rotate. This lowers the efficiency of the turbine as some of the wind's power is used in pushing the convex part and is hence "wasted".

III. LITERATURE SURVEY

Nakajima *et al* (2008) explained the functioning of a savonius wind turbine through an experiment. He showed the various flow pattern of the savonius turbine by visualizing the flow pattern by placing a savonius turbine under the water. He illustrated how the flow patterns result in the operation of the turbine.

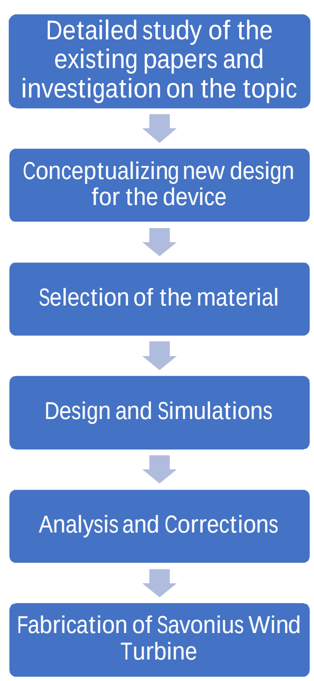
Keum Soo Jeon *et al* (2014) they experimentally studied the effects of end plates on the aerodynamic performance of helical Savonius wind turbines with a twist angle of 180 and two semicircular buckets. In order to investigate both the blockage correction method and the end plate effect, four different helical Savonius wind turbines were tested using a subsonic open-circuit type wind tunnel. The end plate effect shows that the maximum power coefficient and its tip speed ratio linearly increase with the end plate area ratio up to 1.0. Therefore, it turns out that the circular end plate is the best choice for maximizing power and torque coefficients for helical Savonius wind turbines. The use of both upper and lower circular end plates significantly increased the power coefficient by 36% compared with no end plate Vance (1973) the aspect ratio of a Savonius rotor canal so be adjusted to the needs of the rotational rate of the generation system (coupled secondary machine) . Tells that the turbine angular acceleration increases, while the rotor moment M, and inertia of the turbine decrease with increase of the Savonius turbine aspect ratio.

U.K. Saha *et al* (2008) has established the optimum design parameters for a savonius wind through wind tunnel experiments. The paper shows that with the increase in the stages the over all power generation increases. It also suggests that the optimal blade configuration will be two and the power coefficient decreases with increase in blades due to the inefficiency of using the kinetic energy present in the wind. Compared to the three blades and single blade rotor the two blade rotor has better power coefficient. Twisted geometry blade profile performanced better as compared to the semicircular blade geometry.

Rus Tania *et al* (2018) Following this research, the best results regarding the power coefficient were obtained for the Savonius wind turbine with OR 0.30 with an average value of 0.29. These assumptions remain valid even after analysing the amount of energy produced by each rotor. Areas in which there are estimated average annual speeds of wind that doesn't exceed 4 m/s, it is indicated to use Savonius turbines with the OR 0.15. In the case of an average annual speeds higher than 4 m/s or areas where the wind has a turbulent character, Savonius turbine with the OR 0.30 are recommended, to maximize the electricity production.

IV. EXPERIMENTAL METHODOLOGY

The Experiment would be carried out in the below mentioned method . It starts with the detail study of the existing study in harnessing the wind energy. This involves the study of the various experimental investigation on the effect of various design parameters and flow simulation for understanding the optimal design for a wind turbine Using the study improvements could be done to improve the existing design concepts or create new concepts in improving the technology. After conceptualizing the design simulations are done using the design calculation. It is iterated for any corrections in the design and final design is done.



V. DESIGN OF THE SARVONIUS WIND TURBINE

Fig 5.1: Turbine Design

It is considered that it is much better to prevent an unwanted event as over-speeding the turbine, than fighting against it when it has already been produced or is going to occur. It is known that the speed of the turbine, depends directly (among other factors) on the area of the blades. Based on these statements a new concept of turbine was developed.

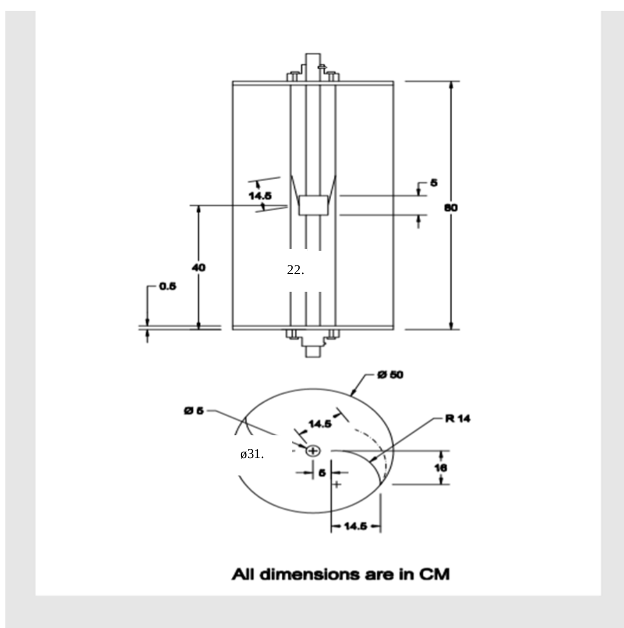


Fig 5.2: Turbine Dimensions

When the rotor blades rotates faster than the set limit the central weight would lift and closes the blades and forms a cylinder shape which would prevent the wind force to rotate the blades future and just reducing the speed of the rotors.

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VI. DESIGN CALCULATIONS

Design parameter calculation are done as follows for determining the specification of the wind turbine:

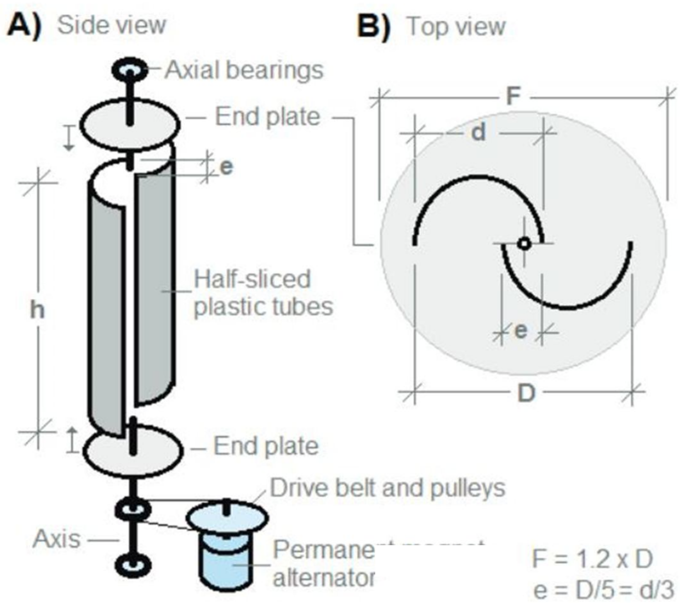

Fig 6.1: Various parameters of the turbine

d – Chord Length [m]
D – Rotor Diameter [m]
e – Overlap [m]
h – Blade Height [m]
v – Wind speed [m/s]
F – Diameter of end plates [m]

A. Calculation Of Various Design Specification

Assume the Rotor diameter D = 0.28 m and Velocity of the wind is 9.8 m/s.
Thickness of the blade is 0.03 m .
The Optimal Specification for the endplate diameter is 1.1 times the rotor diameter.

$$F = 1.1*D \quad (6.1)$$
$$F = 1.1*0.28$$
$$F = 0.31 \text{ m}$$

Optimal Blade Overlap dimension is one fifth of the rotor diameter.

$$e = D/5 \quad (6.2)$$
$$e = 0.28/5$$
$$e = 0.05 \text{ m}$$

The Chord length can be calculated using the rotor diameter as follows

$$D = 2*d - e \quad (6.3)$$
$$d = (D + e)/2$$
$$d = (0.28 + 0.05)/2$$
$$d = 0.17 \text{ m}$$

The Optimal Aspect ratio for an Savonius wind turbine is 0.80

$$H/D = 0.80 \quad (6.4)$$
$$H = 0.80 * 0.28$$
$$H = 0.22 \text{ m}$$

B. Calculation Of Power Produced By The Wind Turbine

Wind turbine convert the Kinetic Energy present in the wind and convert it into Mechanical work which is then converted to electrical energy and stored in the battery using a generator.

$K.E_{wind} = 0.5 * m * v^2$ (6.5)

ower is kinetic energy per unit time

$P = 0.5 * m * v^2$ (6.6)

$P = 0.5 * \rho_{air} * A * v^3$ (6.7)

The power present in the wind is given by

$P_{wind} = 0.5 * \rho_{air} * A * v^3$ (6.8)

Rotor swept area $A = H * D = 0.0655\ m^2$ (6.9)

Assume Velocity to be v = 9.8 m/s

$P_{wind} = 0.5 * 1.225 * 0.0655 * (9.8)^3$ (6.10)

$P_{wind} = 37.75$ Watt

Theoretical Power Produces by the Turbine

According to Betz's law maximum efficiency of a wind turbine is 59%

Hence the maximum power coefficient (C_p) = 16/27

Assuming 50 % loss due to mechanical and aerodynamical losses

$P_{turbine} = C_p * 0.5 * 1.225 * 0.0655 * (9.8)^3 * 0.5$ (6.11)

$P_{turbine} = 11.18$ Watt

Power Coefficient (Cp) = $P_{turbine}/P_{wind}$ = 37.75/11.18 = 0.296

C. Calculation Of Rotational Speed Of The Turbine

Rotational Speed of the Rotor (n) = $(60/2\pi) * \omega$ (6.12)

Angular Velocity (ω) = $(\lambda * v) / r$ (6.13)

Rotor Radius (r) = D/2 = 0.14 m

Tip Speed Ratio (λ) = 1

Tip Speed Ratio can't exceed 1 for a Savonius Turbine as it is a drag type

$\omega = (1 * 9.8) / 0.14 = 70$ rad/sec

n = 9.54 * 70 = 668.45 rpm

D. Calculation Of Torque Of The Rotor Shaft

Torque produced by the wind

$T_{shaft} = P_{turbine} / \omega$ (6.14)

$= 11.18 / 70$

$= 0.1597$ Nm

VII. COMPONENTS USED

Table 7.1: Components used

S.NO.	PARTS	QUANTITY
1	End Plates	2
2	Blades	2
3	Shaft	1

VIII. COMPONENTS DESCRIPTION

A. Mechanical Components

1) *Shaft:* The shaft is connected to the blades and rotates as the wind produce torque through the blades. The shaft is connected to the housing where this rotation is converted to electrical energy.

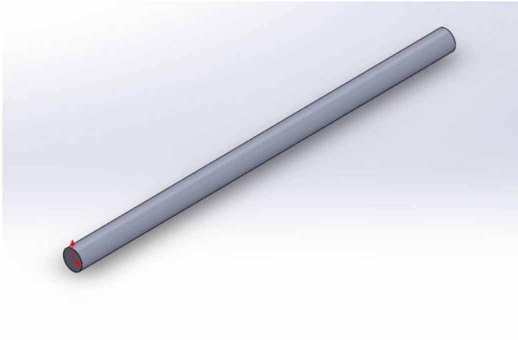

Fig 8.1: Shaft

Shaft Diameter = 0.05 m
Shaft Length = 0.90 m

2) *Rotor Blades:* They are mainly made of aluminum, fiber glass or carbon fiber because they provide batter strength to weight ratio.Over all performance of the turbines are affected by the design of individual blades. Rotor blades capture the wind energy and converts them into mechanical energy by rotating the shaft. .

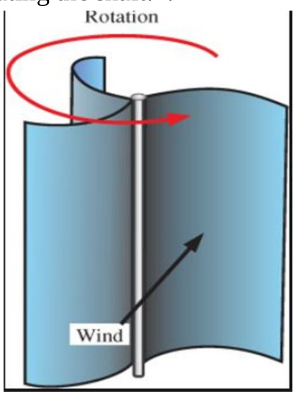

Fig 8.2: Rotor Blades

3) *End Plates:* End Plates gives better efficiency to the wind turbine by preventing air flow from entering perpendicular to the stream of flow to air through the turbine.

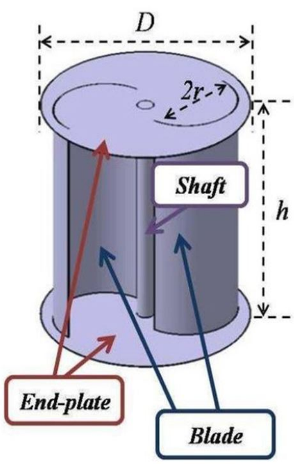

Fig 8.3: End Plates

IX. RESULT AND CONCLUSION

The pressure and velocity analysis are done to analyze the effectiveness of the concept. Below are the results of the analysis of the closed position of the blade and open position of the blades.

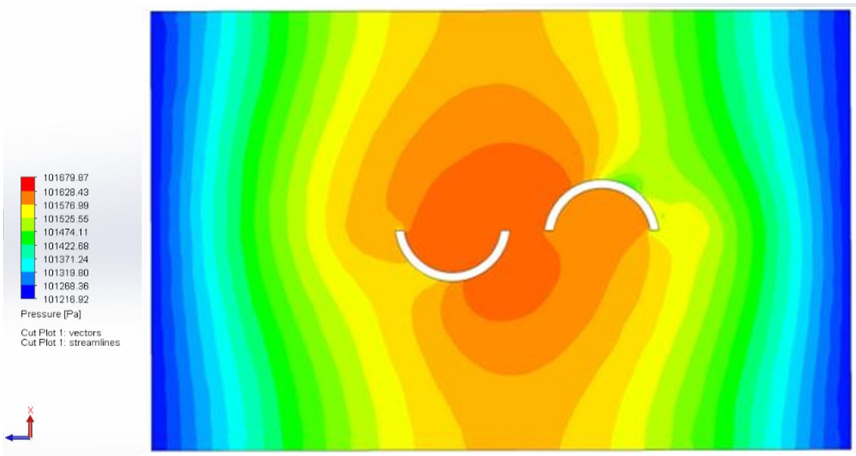

Fig 9.1: Pressure contour in open condition

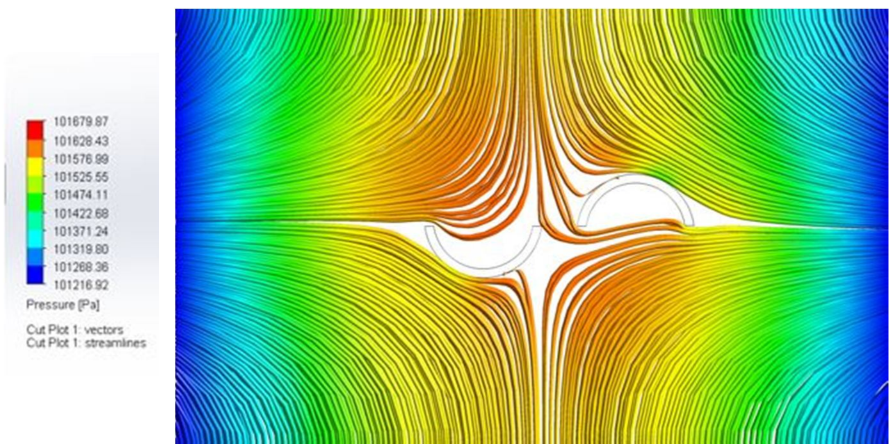

Fig 9.2: Pressure streamline in open condition

Fig 9.1 and Fig 9.2 shows the pressure contour and the streamline of the wind flow. The red region is the location at which the blades are facing maximum pressure. The Global Maximum Pressure for the closed position blades are 101679.87 Pa and the Global Minimum Pressure is 101218.92.

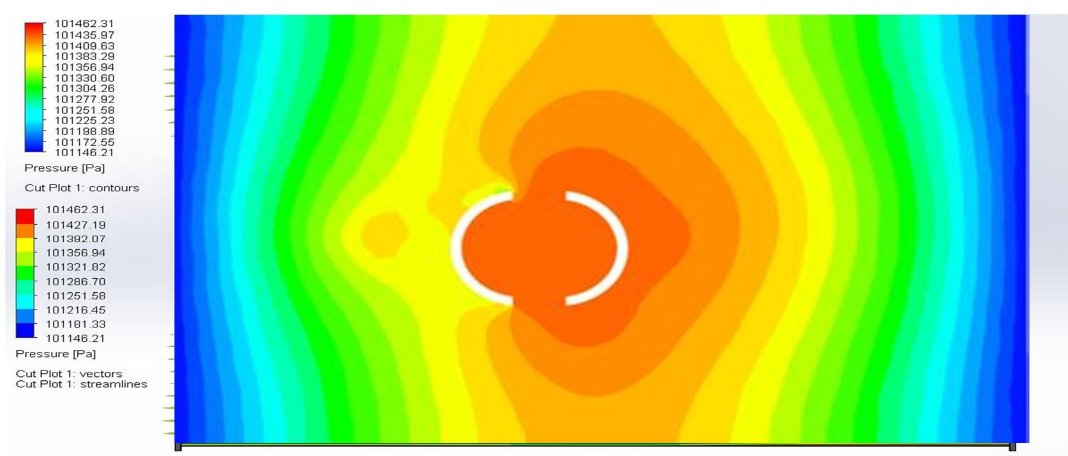

Fig 9.3: Pressure contour in closed condition

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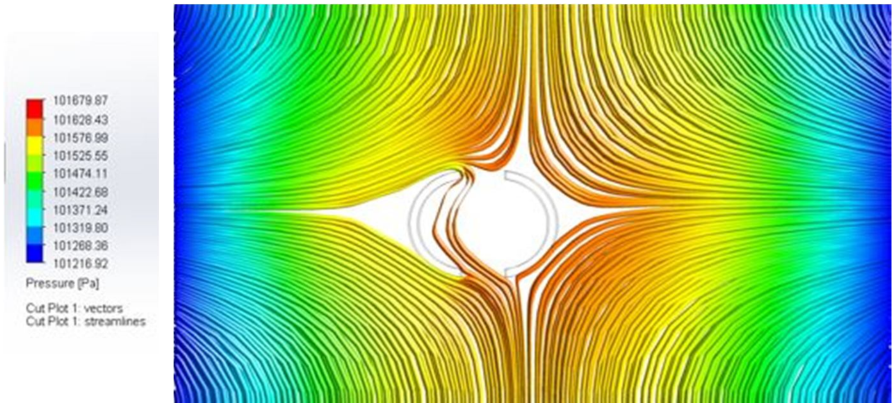

Fig 9.4: Pressure streamlines in closed condition

Fig 9.3 and Fig 9.4 shows the pressure contour and streamline analysis of the Open position blades. The Global Maximum and Global Minimum Pressure are 101462.31 Pa and 101146.21 Pa respectively.

When we compare both conditions Global Maximum Pressure and Global Minimum Pressure we can see that there is considerable reduction in the pressure which indicates that due to the change in the shape there is a reduction in the pressure action on the blades hence reduction in the drag force acting on the blades.

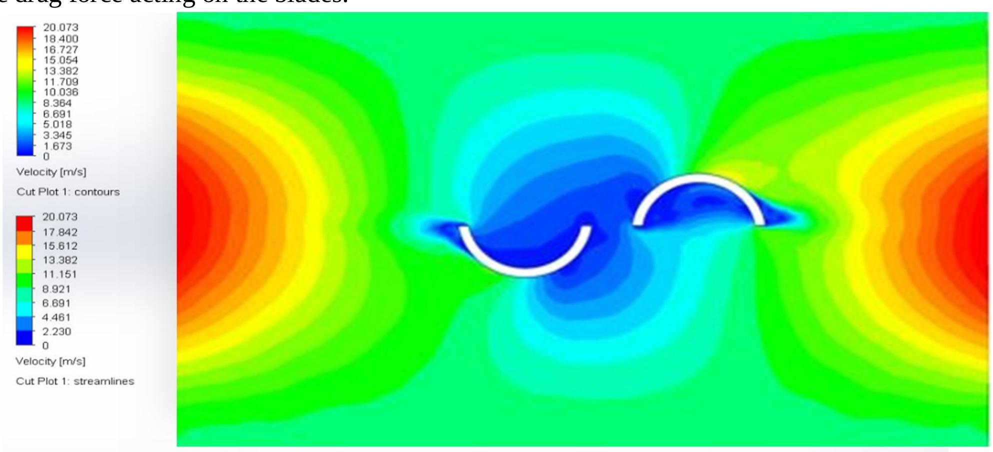

Fig 9.5: Velocity contour at open condition

Fig 9.5 shows the velocity contour analysis for the open blade conditions with global maximum of 20.073 m/s and global minimum of 0 m/s.

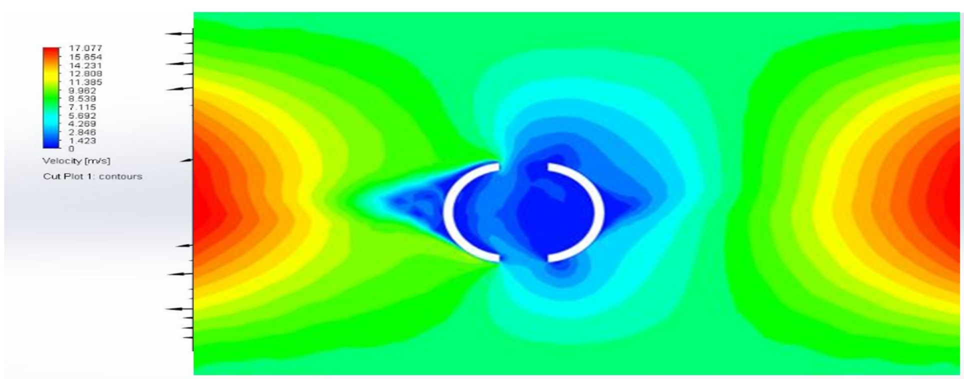

Fig 9.6: Velocity contour at closed condition

The above is the velocity contour analysis for the closed blade conditions with global maximum of 17.077 m/s and global minimum of 0 m/s.

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With the observation we can conclude that the velocity of the rotor reduces when the blades change their shape. Thus preventing blade damage during high velocity conditions.

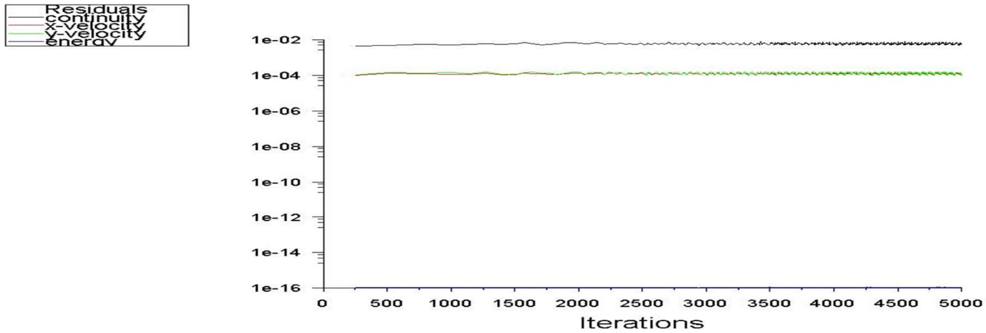

Fig 9.7: Residual plots at open condition

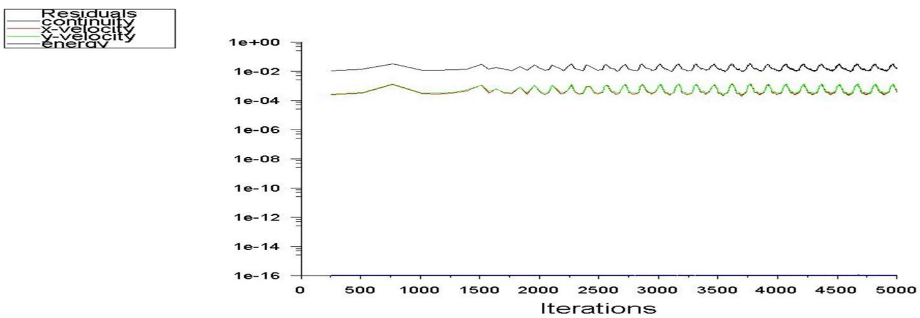

Fig 9.8: Residual plots at closed condition

Appendices

Fig 10.1: Fabrication of the turbine

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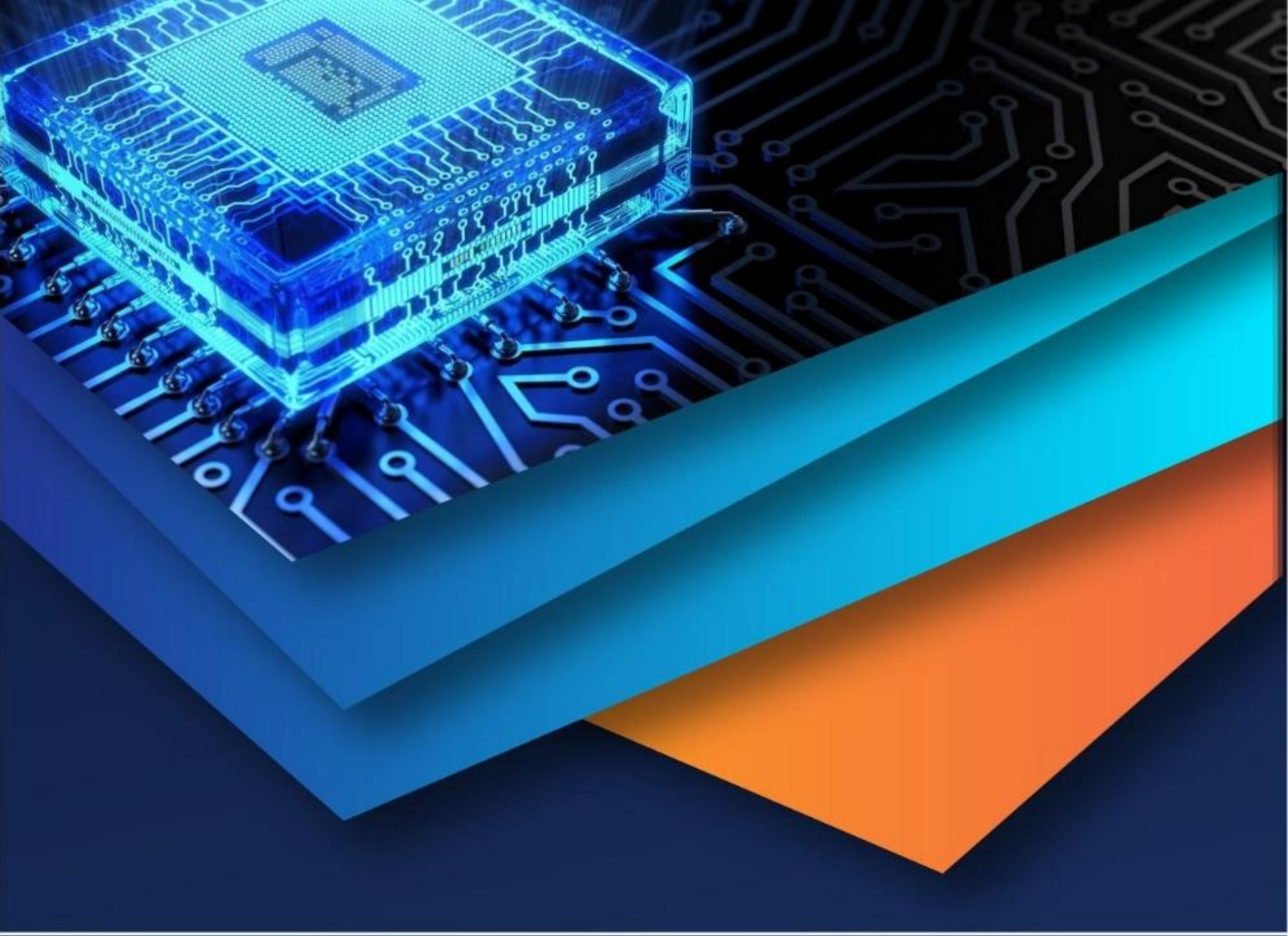

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