Design of Horizontal Axis wind Turbine Casing and Nozzle

Prof S. B. Teli,Vaibhav Mundiwale, Hardik Padariya

Mechanical Engineering Department, SKNCOE, Savitribai Phule Pune University

***Abstract*—** The methods used for producing energy are threatening to deplete the natural resources which are non-renewable in nature. Hence to avoid this danger, safer methods are given more preference which can use renewable sources of energy. The renewable energy resources include solar, wind, tidal, geothermal, biomass, etc. Out of these sources, wind energy is the least used renewable source of energy.
Wind energy provides the wind force which can be used as mechanical energy to rotate a turbine to generate electrical energy. The wind energy on the highways is greater than the residential areas. Here, the natural wind flow is free to move unobstructed by trees or buildings down a highway and would be ample enough to turn the blades of the turbines. The relative wind velocities produced by passing traffic would act in conjunction with the natural wind to increase the angular velocity of the blades.
In this project, we have designed a Horizontal Axis Wind Turbine (HAWT), which utilizes the wind energy present on the highways to produce electrical energy. A nozzle is attached on the entrance, which increases the velocity of the flow of air, thereby increasing the force exerted on the blades of the turbine. This causes an increase in the angular velocity of the shaft and hence the magnitude of the electricity generated increases. The turbine used has blades at an angle which allows it to rotate when air will be incident on the blades. The turbine is made of plastic which is lighter in weight as compared to a similar size aluminium turbine. The turbine shaft rotates due to the rotation of blades and a generator is used to convert the mechanical energy into electrical energy. This electrical energy can be directly connected to the power grid or can be stored in batteries for further use.

I. Introduction

The ill–effects of climate change have been becoming more severe and prevalent over the last decade or so. The cause has been identified as greenhouse gas emissions from the burning of fossil fuels. For this reason, there has been a pressing need to reduce emissions using technologies that are capable of extracting energy from the environment whilst being non–polluting and sustainable. Several alternative sources to fossil fuels have been identified with wind as one of the most promising

In current years, wind power has turned out to be one of the majority inexpensive renewable energy information. Today, electrical energy generating wind turbines employ proven and tested technology and provide a sustainable energy supply. At open lands and highways, wind energy can successfully compete with conventional energy production.

Wind turbine may be an alternative for electricity generation in the areas of non-electrical grid power supply. There are two types of wind turbine, vertical axis wind turbine and horizontal axis wind turbine. The vertical axis wind turbine has an assembly of rotor which revolves about its vertical axis.

Many countries have great breeze resources which are still unused. The growth of wind power in India began in the 1986 with first wind farms being set up in Maharashtra, Gujarat and Tamil Nadu with 55 kW wind turbines. The capacity has considerably increased in the last few years. They are new comer to the wind industry compared with the United States. India has the 4th major installed wind power capacity in the world. In 2009-10 India's growth rate was highest in the middle of the other top four countries.

Wind power generation capacity in India has significantly increased in recent years. As of 28 February 2018, the total installed wind power capacity was 32.96 GW, the fourth largest installed wind power capacity in the world. Wind power capacity is mainly spread across the south, west and north regions.

Wind power cost in India are decreasing rapidly. The levelized tariff of wind power reached a record low of 2.43 rupees per KW h during auctions for wind projects in December 2017.

With the development of electric power, wind power found new applications in lighting buildings remote from centrally-generated power. Throughout the 20th century parallel paths developed small wind stations suitable for farms or residences, and larger utility-scale wind generators that could be connected to electric power grids for remote use of power. Today wind powered generators operate in every size range between tiny stations for battery charging at isolated residences, up to near-gigawatt sized offshore wind farms that provide electric power to national electrical networks.

A. Wind Energy

Wind energy describes the process by which wind is used to generate electricity. Wind turbines convert the kinetic energy in the wind into mechanical power. A generator can convert mechanical power into electricity.

Wind power, as an alternative to burning fossil fuels, is plentiful, renewable, widely distributed, clean, produces no greenhouse gas emissions during operation, consumes no water, and uses little land. The net effects on the environment are far less problematic than those of non-renewable power sources.

Wind is caused by the uneven heating of the atmosphere by the sun, variations in the earth's surface, and rotation of the earth. Mountains, bodies of water, and vegetation all influence wind flow patterns. Wind turbines convert the energy in wind to electricity by rotating propeller-like blades around a rotor. The rotor turns the drive shaft, which turns an electric generator. Three key factors affect the amount of energy a turbine can harness from the wind: wind speed, air density, and swept area.

Equation for Wind Power

$$P = \frac{1}{2}\rho A V^3$$

Wind speed: The amount of energy in the wind varies with the cube of the wind speed, in other words, if the wind speed doubles, there is eight times more energy in the wind. Small changes in wind speed have a large impact on the amount of power available in the wind.

Density of the air: The denser the air, the more energy received by the turbine. Air density varies with elevation and temperature. Air is less dense at higher elevations than at sea level, and warm air is less dense than cold air. *All else being equal*, turbines will produce more power at lower elevations and in locations with cooler average temperatures.

Swept area of the turbine: The larger the swept area (the size of the area through which the rotor spins), the more power the turbine can capture from the wind. Since swept area is pir^2, where r = radius of the rotor, a small increase in blade length results in a larger increase in the power available to the turbine.

B. Wind Turbine

A wind turbine is a device that converts the wind's kinetic energy into electrical energy. Wind turbines are manufactured in a wide range of vertical and horizontal axis types.

The smallest turbines are used for applications such as battery charging for auxiliary power for boats or caravans or to power traffic warning signs. Slightly larger turbines can be used for making contributions to a domestic power supply while selling unused power back to the utility supplier via the electrical grid.

Arrays of large turbines, known as wind farms, are becoming an increasingly important source of renewable energy and are used by many countries as part of a strategy to reduce their reliance on fossil fuels. Wind was shown to have the "lowest relative greenhouse gas emissions, the least water consumption demands and the most favorable social impacts" compared to photovoltaic, hydro, geothermal, coal and gas.

C. Types of Wind Turbines:

Mainly the wind turbines are classified on the basis of the orientation of their shafts. There are two types of wind turbine. They are:

- Horizontal Axis Wind Turbine (HAWT)
- Vertical Axis Wind Turbine (VAWT)

D. Horizontal-axis Wind Turbine (HAWT):

Horizontal-axis wind turbines (HAWT) have the main rotor shaft and electrical generator at the top of the tower and may be pointed into or out of the wind. Small turbines are pointed by a simple wind vane, while large turbines generally use a wind sensor coupled with a servo motor. Most have a gearbox, which turns the slow rotation of the blades into a quicker rotation that is more suitable to drive an electrical generator.

The lifting style wind turbine blade. These are the most efficiently designed, especially for capturing energy of strong, fast winds. Some European companies manufacture a single blade turbine.

The drag style wind turbine blade, most popularly used for water mills, as seen in the old Dutch windmills. The blades are flattened plates which catch the wind. These are poorly designed for capturing the energy of heightened winds.

The rotor is designed aerodynamically to capture the maximum surface area of wind in order to spin the most ergonomically. The blades are lightweight, durable and corrosion-resistant material. The best materials are composites of fiberglass and reinforced plastic

A gear box magnifies or amplifies the energy output of the rotor. The gear box is situated directly between the rotor and the generator. A rotor rotates the generator (which is protected by a nacelle), as directed by the tail vane.

The generator produces electricity from the rotation of the rotor. Generators come in various sizes, relative to the output you wish to generate. The nacelle is the housing or enclosure that seals and protects the generator and gear box from the elements. It is easily removed for maintenance of the wind.

The tail vane directs the turbine to gather maximum wind energy.

Type of wind the HAWT works best in

In general, annual average wind speeds of 5 meters per second (11 mph) are required for grid connected applications. Annual average wind speeds of 3 to 4 m/s (7-9 mph) may be adequate for non-connected electrical and mechanical applications such as battery charging and water pumping. Wind resources exceeding this speed are available in many parts of the world. A useful way to evaluate the wind resource available at a potential site is the wind power density

Typical lifespan

The lifespan of a modern turbine is pegged at around 120,000 hours or 20-25 years however, they are not maintenance free. As they contain moving components, some parts will need to be replaced during their working life. Throughout research, the cost

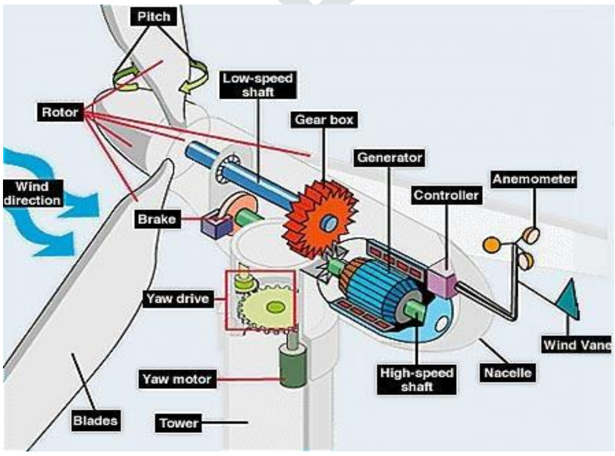

Fig 1. Parts of the wind turbine

of maintenance and parts replacement is around the 1 cent USD/AU per kWh or 1.5 to 2 percent annually of the original turbine cost.

HAWT Gearboxes

The gearboxes in the traditional horizontal axis wind turbines currently have an average life span of 1.5 years. Replacing these gearboxes can be extremely costly.

Type of wind the HAWT works best in

In general, annual average wind speeds of 5 meters per second (11 mph) are required for grid connected applications. Annual average wind speeds of 3 to 4 m/s (7-9 mph) may be adequate for non-connected electrical and mechanical applications such as battery charging and water pumping. Wind resources exceeding this speed are available in many parts of the world. A useful way to evaluate the wind resource available at a potential site is the wind power density

Typical lifespan

The lifespan of a modern turbine is pegged at around 120,000 hours or 20-25 years however, they are not maintenance free. As they contain moving components, some parts will need to be replaced during their working life. Throughout research, the cost of maintenance and parts replacement is around the 1 cent USD/AU per kWh or 1.5 to 2 percent annually of the original turbine cost.

HAWT Gearboxes

The gearboxes in the traditional horizontal axis wind turbines currently have an average life span of 1.5 years. Replacing these gearboxes can be extremely costly.

II. Literature Review

The design of our model “Horizontal axis wind turbine” has been done keeping in mind that the minimum velocity required to rotate the turbine is available on highways and open barren lands at higher altitude. The nozzle is designed in such a way that it will accelerate the motion of the incoming air. The nozzle converts the pressure energy of air into kinetic energy. The air entering through the nozzle hits the blades above the axis of the rotor and at an angle which is approximately 60°. This causes the air to hit the blades at right angle to apply maximum force. The rotor is set into motion due to this force, and this rotates the shaft attached to it. Bearings are used to align the shaft and eliminate the forces on it, thus allowing the shaft to rotate freely. The shaft is directly coupled to the shaft of the dc motor. When the rotor rotates, the shaft of the motor is set in motion and this causes the generation of electrical energy. This energy can be stored in batteries or directly connected to the power grid. The model can be further modified by changing the shape and materials used to increase the generation of electrical energy. The modified system can be used for practical applications such as wind energy generations on highways. The whole system is compact and can be used on areas where high velocity winds are available. It can be used to produce clean energy without the risk of harming the environment.

III. Design Considerations

A. Material Selection

1. *Shaft*: The material used for shaft is mild steel. It provides good strength, ductility and malleability at lower prices. This is because mild steel can be easily machined in the lathe, drilling or milling machine. It is also available easily in market. We have used 8mm shaft on both the sides.
2. *Turbine:* We have selected a blower wheel for rotor. It has 34 blades and is made of plastic. It has a fixed shaft on one end and a hole of 8mm for another shaft on the other side. It has blades attached at an angle, which will experience the force of the wind and is hollow from inside.
3. *Nozzle and Casing:*We have selected mild steel of 3 mm thickness for the fabrication of the nozzle and circular casing. Mild steel can be easily welded while performing assembly and it can be easily rolled. It is enough strength to withstand high velocity of winds in certain extreme situations.
4. *Bearing*: We have selected spherical ball bearings with inner diameter of 8mm for both the shafts and outer diameter of 22 mm. The bearings are strong enough to withstand the forces on the shaft. It is then further fitted in mild steel plates of 6mm thickness in order to prevent any damage to it due to less diameter of the casing.
5. *DC Motor:* We have used Mabuchi RS-555PH 12 V dc motor for converting the mechanical energy of the rotating shaft into electrical energy which can be stored in batteries or connected directly to the power grid. The specifications of the motor are as follows:
   - Operating Voltage range: 12V-36V
   - Rated Voltage: 24V
   - Rated Current: 0.7A
   - Rated Torque: 62 mN.m
   - No load speed: 4100 rpm
   - Motor weight: 230g
   - Resistance: 1.6 Ω

B. Design of the Model

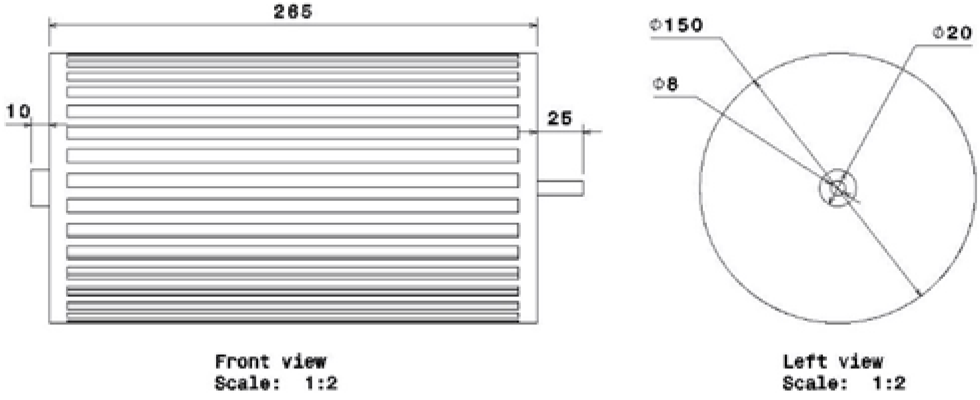

Fig 2. Front view and Left view of the rotor

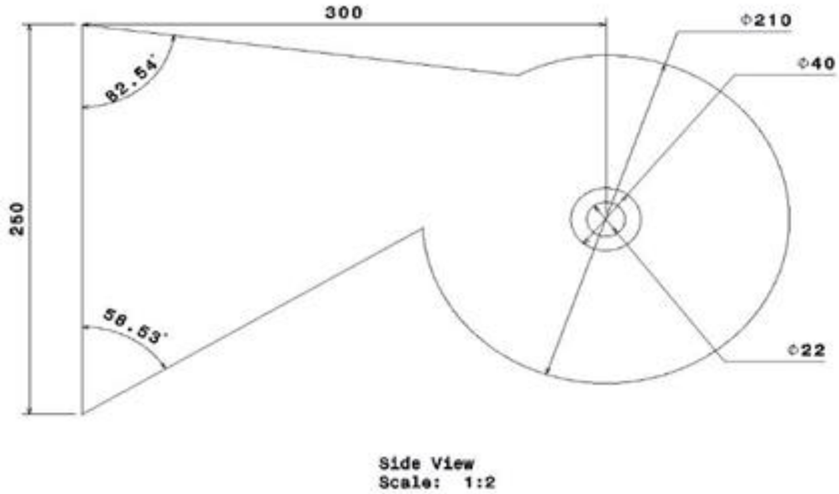

Fig 3. Side View of the Model

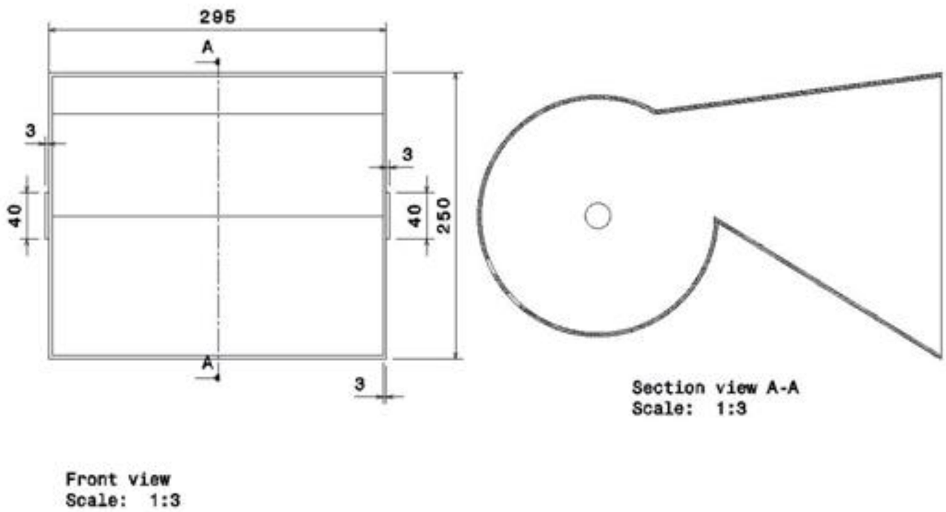

Fig 4. Front view and section view of nozzle and casing

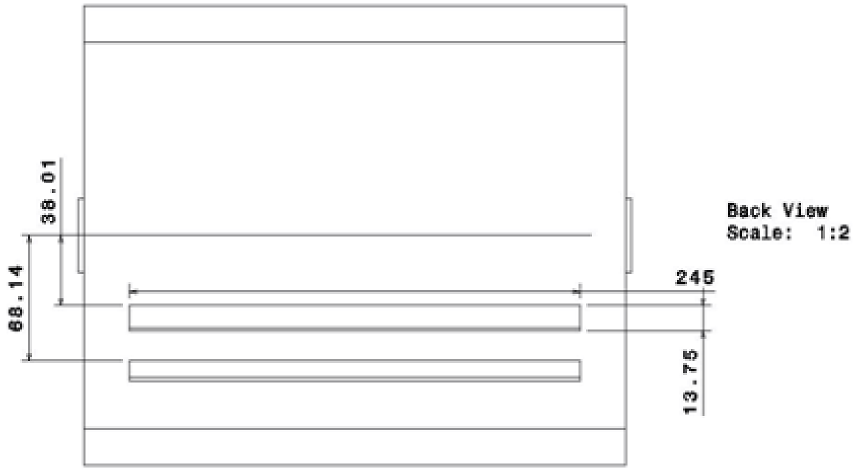

Fig 5. Back view of the casing with slits

C. CFD Analysis of the Model

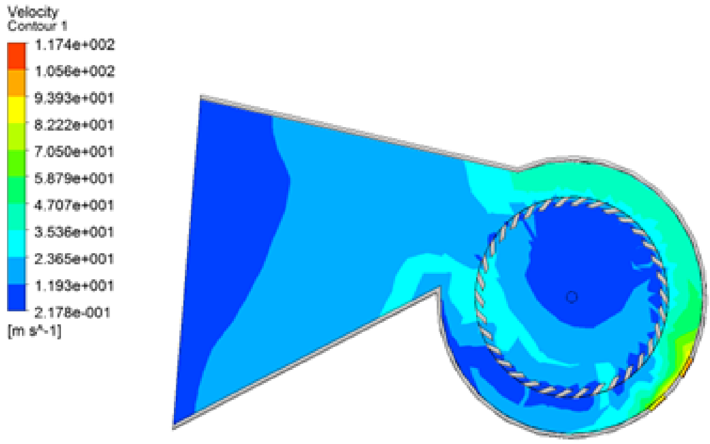

Fig 6. Left view of Velocity Contour

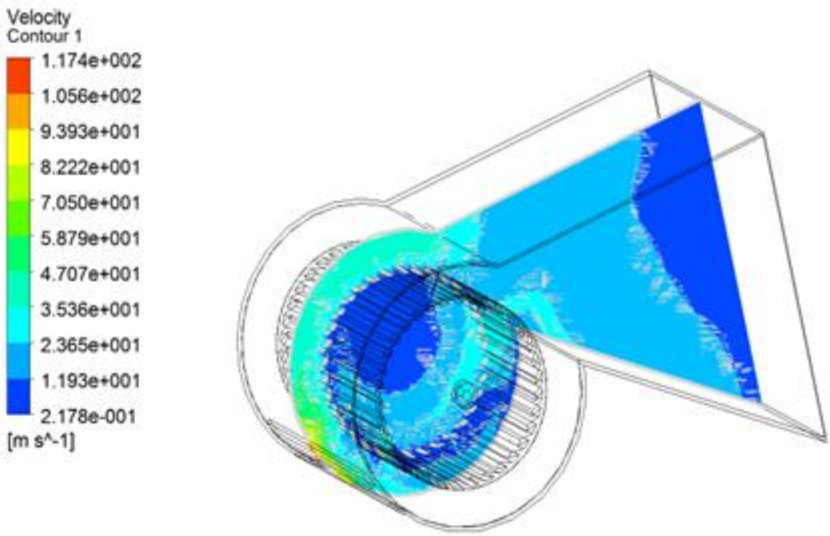

Fig 7. Right view of Velocity Contour

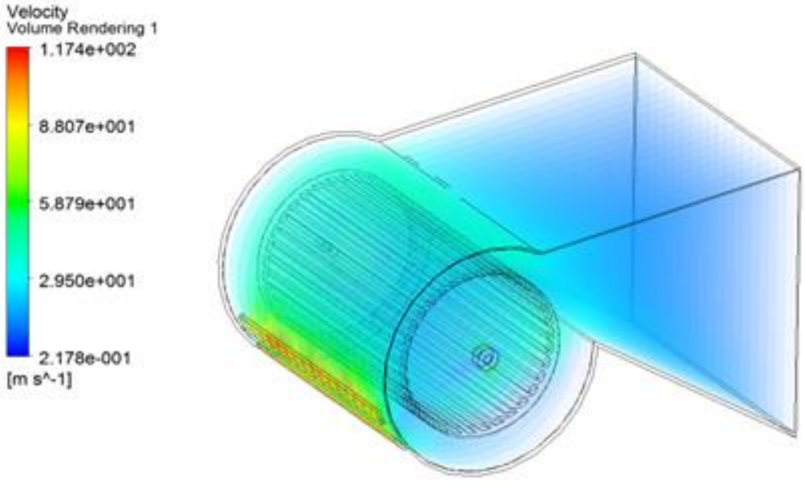

Fig 8. Left view of Pressure View

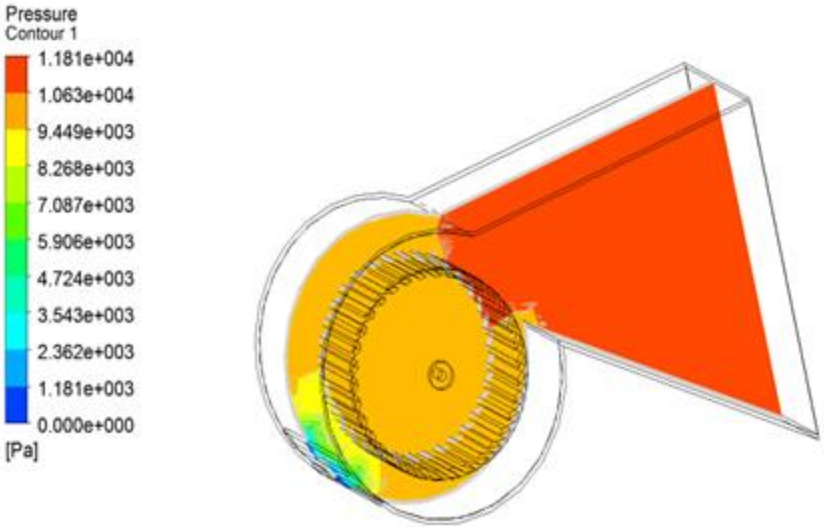

Fig 9. Right view of Pressure Contour

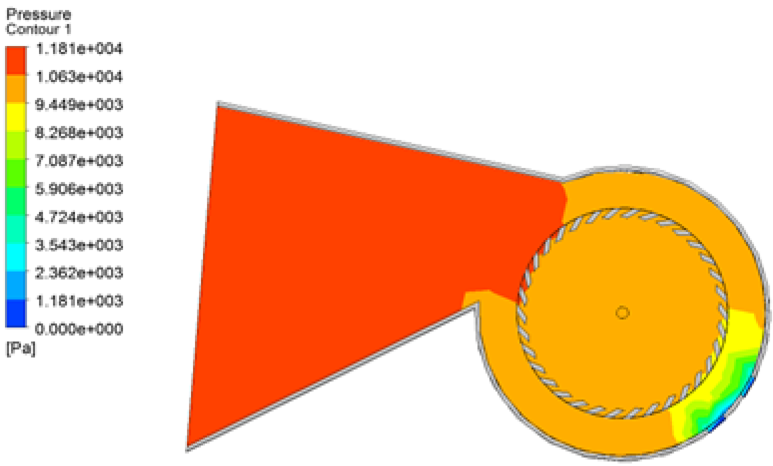

Fig 10. Left view of Velocity Volume Rendering

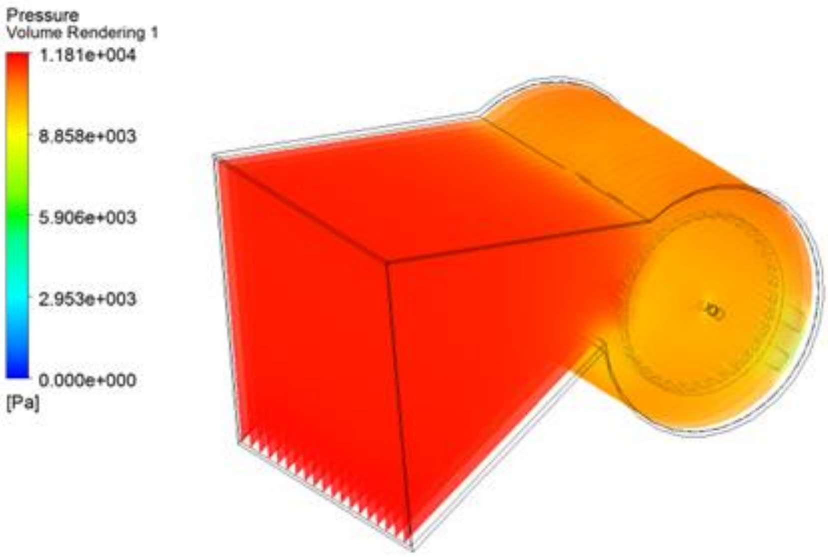

Fig 11. Right view of Velocity Volume Rendering

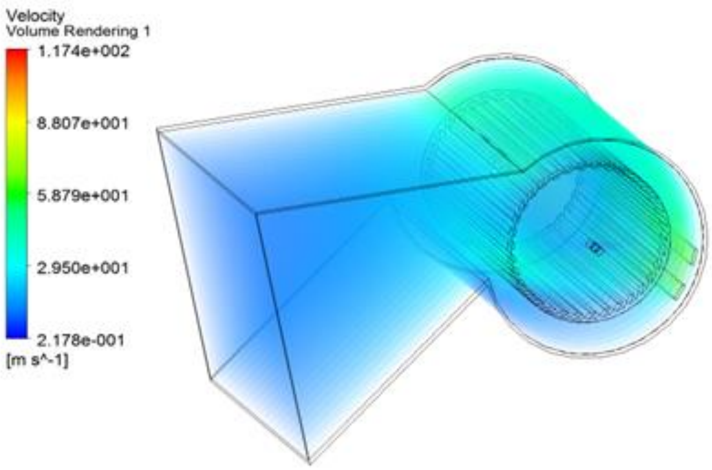

Fig 3.22. Left view of Velocity Streamline

D. Design Calculations

Turbine Calculations:

Design of wind turbine starts with swept area (A)
Height (Width) of the rotor = 265 mm
Diameter of the rotor = 150 mm
Area Calculations of Turbine

$$\text{Area} = H * D$$
$$= 265 * 75$$
$$= 19875\ mm^2$$
$$\underline{\text{Area} = 0.019875\ m^2}$$

Design and Calculations is done by considering the velocity of wind that will hit the blade and kinematic viscosity (υ), air density(ρ) and no. of blades.

Tip Speed Ratio (TSR)= λ =1
TSR = 1-4 for small scale energy generation
TSR = 5-9 for large scale energy generation
Numbers of blade (N_b) = 34
Wind Velocity (v) = 8 m/s
Kinematic Viscosity of air (υ) = 0.0000178 kg/m.s
Air Density (ρ) = 1.20 kg/m^3

- Wind Power Available

$$P_w = \frac{1}{2} * \rho * A * v^3$$

$$= \frac{1}{2} * 1.2 * 0.01987 * 8^3$$

$P_w = 6.1056$ W

- Mechanical power can be calculated by:

$$P_m = P_w * C_p$$
$$= 6.1056 * 0.59$$
$$P_m = 3.6023 \text{ Watts}$$

Here C_p denotes Bitz limit or coefficient of power which states that a wind turbine gives maximum of efficiency of 59 %.
$C_p = 0.59$

- Angular Velocity (ω):

$$\omega = 10.667 \text{ Rad/s}$$

- Number of Revolutions (N):

$$N = 101.854 \approx 102 \text{ rpm}$$

- Lift force which causes blade to lift

$$F_e = 1.0923 \text{ N}$$

- Drag Force which restricts the wind speed :

$$F_d = 0.054616 \text{ N}$$

- Transmitted Torque

$$T = 5.71609 \text{ Ncm}$$

Nozzle Calculations:

By using continuity equation, calculate the theoretical velocity at the outlet of nozzle which is then further connected to the turbine

$$Q = A_1V_1 = A_2V_2$$
$$A_1V_1 = A_2V_2$$
$$(295*10^{-3})*(250*10^{-3})*8 = (295*10^{-3})*(250*10^{-3})V_2$$

$V_2 = 20$ m/s

- Flow Rate

$$Q = (295 * 250 * \frac{8}{60}*10^{-6})$$
$$Q = 9.833334 \text{ m}^3/\text{s}$$

Motor Calculations:

The DC Motor that we have used has the following specifications:

Diameter of Motor = 3 mm
Length of Motor = 21 mm
Rated Current = 380 mA
Rated Voltage = 12 V DC
No. of revolutions = 4100 rpm
Resistance of Coil = 1.6 Ω
Rated Torque = 62 m Nm

- Static Power required by the motor

$$P_{I/P} = M_t * \omega$$
$$P_{I/P} = 62 * 10^{-3} * 10.667/60$$

$P_{I/P} = 11.0225667$ mW

- Power generated by the motor

$$P_{O/P} = I * V$$
$$P_{O/P} = 380 * 12 * 10^{-3}$$
$$\underline{P_{O/P} = 4.56\ W}$$

Hence, the above are the overall calculations required for the estimations of the power required for the motor and the rotor to rotate and the output voltage which will be available for use. Also, the nozzle velocity calculations are also performed. The practical output will slightly differ from these theoretical calculations.

IV. COST ESTIMATION

A. Cost of Mechanical Components

SR NO	NAME OF THE COMPONENT	COST INCURRED (RS)
1	BLOWER WHEEL	400
2	SHAFT	20
3	BEARINGS	80
4	MILD STEEL SHEETS OF 3 MM THICKNESS	580
5	TOTAL COST	1080

B. Cost of Electrical Components

SR NO	NAME OF THE COMPONENT	COST INCURRED (RS)
1	DC MOTOR	400
2	MULTIMETER	1000
3	CONNECTING WIRES	200
4	TOTAL COST	1600

V. CONCLUSION

- The generation of energy from wind turbines is totally pollution free and does not create any waste products.

Our model is compact in nature and can be transported and installed easily in any desired location.

- The operational cost of the model is negligible.
- The main cause of concern in the functioning of the wind turbines is the lack of wind speed in some areas. We have tried to tackle this situation by designing a suitable nozzle for increasing the kinetic energy of the incoming wind, which in turn increases the output voltage.
- We have used slits instead of exhaust pipe for the removal of the used air. This decreases the size and cost required for the model.

VI. REFERENCES

[1] S. V. Saravanan, M. Varatharaj, L. Ayyadurai, S. Palani and D. Prem "Design and Fabrication of Vertical Axis Highway Windmill"

[2] SumpunChaitep, TanateChaichana, PipatpongWatanawanyoo, Hiroyuki Hirahara "Performance Evaluation of Curved Blades Vertical Axis Wind Turbine"

[3] Ali S. Bazgir "Theoretical Concepts for Utilizing Nozzle between the Wind-way and Wind Turbine in Roof of the Buildings- Wind Speed Increase for Wind Turbine to Produce Electricity"

[4] MagediMoh M. Saada, Sofian Bin Mohd, MohdFadhliZulkaflia "Power generation of small wind turbine: Under high-speed operation"

[5] CatalinHarabagiu, Mihaela Adochitei, Radu Burlicain "Effect of a Semi-Cylindrical Wind Shield on the Power Output of a Vertical Axis Wind Turbine"

[6] R. Bravo, S. Tullis, S. Ziada "Performance Testing of a Small Vertical-Axis Wind Turbine"

[7] Louis Angelo Danao, Jonathan Edwards, OkeogheneEboibi, Robert Howell "The Performance of Vertical Axis Wind Turbine in Fluctuating Wind – A Numerical Study"

[8] J.M. O'Brien, T.M. Young, J.M. Early, P.C. Griffin "An assessment of commercial CFD turbulence models for near wake HAWT modelling"

[9] Sudhamshu A.R., Manik Chandra Pandey, Nivedh Sunil, Satish N.S., Vivek Mugundhan, Ratna Kishore Velamati "Numerical study of effect of pitch angle on performance characteristics of a HAWT"

[10] Asis Sarkar, Dhiren Kumar Behera "Wind Turbine Blade Efficiency and Power Calculation with Electrical Analogy"