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STUDY OF VERTICAL AXIS WIND TURBINE FOR POWER GENERATION

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Abstract- *In an effort to find solutions for global energy crisis, an analysis on vertical axis wind turbine was conducted with the consideration of renewables and energy efficiency. This study was carried out based on simulation. Various types of blades with various parameters are simulated to find out lift and drag forces. Hence the forces are used to calculate the power output. It was observed that 500 mm height and 125 mm curvature radius is best of all barrel and helical designs we have done for air velocity of 5 m/s. In case of icewind blade, height 500 mm and curvature radius 250 mm gives best performance. In case of simulation, tip angle plays a vital role to give the output results. It was concluded that the icewind blade is the best design which gives the largest output power, and recommended for any practical purpose.*

Keywords: VAWT, ANSYS simulation, Pressure drop, Torque.

1. INTRODUCTION

The term wind energy or wind power refers to the use of air flow through wind turbines in order to provide mechanical work which later is converted to electrical energy. Wind power is considered as the sustainable or renewable alternative to the burning fossils energy [1]. However, its use as a means of electricity supply began modern era due to the rise of environmental concerns and fuel resources issues. The global demand for sustainable and renewable energy has created the necessity for research and the development of new technology. Hence, the wind energy has been the focus of the industry and has considerably grown its use but just in a large scale production [2].

Bangladesh is suffering severely from power crisis in past few years. Fossil fuels are getting diminished day by day. Bangladesh should look for renewable sources of energy. Wind can be a solution to this problem. Among all the renewable sources, wind is the most promising one. Although mankind has been using the wind energy since ancient time, its use to produce electricity effectively by means of modern wind turbines is over two decades old [3]. Bangladesh is arranged between 20.30 - 26.38 degrees North scope and 88.04 - 92.44 degrees East. It has almost 700 km beach front line. Investigation of upper air information by CWET India demonstrates that breeze vitality asset of Bangladesh isn't sufficient for network associated wind parks. Be that as it may, at present, a few research works are experiencing primarily by Bangladesh Power Improvement Board (BPDB), all around upheld by Bangladesh University of Engineering and Technology (BUET). It has been now discovered that, it is doable to set up little wind turbines in beach front zones. Next to specialized practicality, financial achievability should be very much characterized to allure the speculators [4]. During Rainstorm, the solid south/south-westerly wind originating from the Indian Sea; goes into Asia. This breeze goes through the beach front zone of Bangladesh. This breeze blows over the outside of Bangladesh from Spring to September, having a normal speed of 3 m/s to 6 m/s. During October to February, wind speed remains generally lower. The most extreme breeze speed is picked up during June-July. Setting up wind turbine in waterfront zones can be a superior answer for help the national network. Other than these spots, there are a ton of bumpy areas and segregated islands in Bangladesh; where wind is accessible at a normal speed of 2 m/s to 5 m/s all the year [5]. During the April-May, demand of electricity is on the peak in Bangladesh due to the launching of summer accompanied by heavy demand of water in irrigation purpose. Curiously, in the greater part of the areas (in any event half) of Bangladesh suction head in Bangladesh is just 6 meter. For the most part, the required siphon is of 12 meters head and 2 cusec limit. This interest can without much of a stretch be met by saddling the breeze potential. Presently, this interest is fundamentally satisfied by diesel. Power age cost by diesel is generally higher than different fills. Establishment of windmills won't just spare the greater expense of siphoning water for water system reason yet in addition increment the national power age from a trustworthy source [6].

There are two types of wind turbine: horizontal axis wind turbine (HAWT) and vertical axis wind turbine (VAWT). In horizontal axis wind turbine, the rotational axis of this turbine must be oriented parallel to the wind in order to produce power. Numerous sources claim a major efficiency per same swept area and the majority of wind turbines are of this type. Currently horizontal axis turbines are the most used due to its higher performance featuring high winds, easy maintenance and low cost. Although there are various configurations of wind turbines, one blade, two blades, three and Multi blades, removing the one blade and multi blades which are for special cases, the two blades and three blades are the most used. But the three blades are used more because its energy produced is greater and its robustness makes them stronger to stronger winds and it is created less impact visual [7]. In vertical axis wind turbine, the rotational axis is perpendicular to the wind direction or the mounting surface. The main advantage is that the generator is on ground level so they are more accessible and thus don't need a yaw system. Because of its proximity to ground, wind speeds available are lower. It is a vertical axis machine, very simple from the standpoint of constructive and operational. Besides simplicity, has the advantage of being very robust and have a strong starting torque, that possible the starting even with very weak winds. But can be used only with reduced powers and that the turbine works well with light winds, while its yield decreases with high winds and even becomes vulnerable, so their size cannot exceed certain limits [8].

The wind energy is the kinetic energy of air in motion. When such energy passes through the turbine rotor, the kinetic energy is transformed into mechanical energy which makes the blades starting to move. The power output of the wind turbine is given by following equation.

$$P = \frac{1}{2}\rho A v^3 \quad (1)$$

Where,
P=Power output (W)
A=Sweep area (m^2)
ρ =Air density (Kg/m^3)
v=Wind velocity (m/s)

The equation shows the velocity cubed (v^3), the rotor sweep area, the air density and the turbine and generator efficiencies, hence, it is important to contemplate the turbine size to catch most out of the air mass, the installation place and the wind speed conditions [9].

The objectives of present study are to design three different types of blade (barrel, helical, icewind) of VAWT, to analyze optimum conditions for three blades by changing blade height and blade curvature, to determine and analyze the pressure drop and momentum of blades with ANSYS simulation and finally to find out the best one VAWT from that three types of design.

2. MATERIALS AND METHODS

2.1 CAD Models

1. Barrel Blade*:* Two types of Barrel blades of 125 mm and 140 mm curvature radii with 500 mm height are selected and designed to perform the simulation. A barrel blade of 140mm curvature radius is shown in Fig. 1.

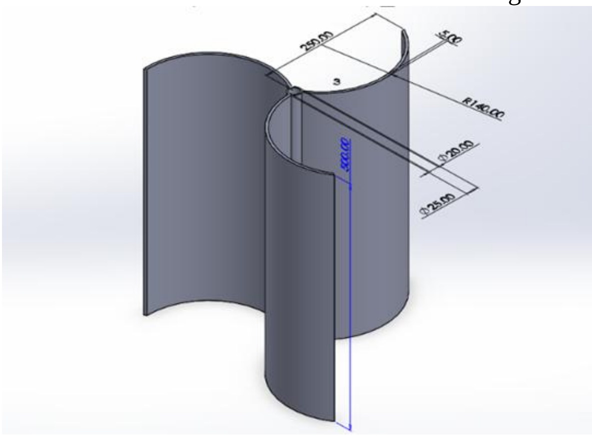

Fig. 1: Barrel blade of 140mm curvature radius

2. Helical Blade: Helical blades have inclination between top and bottom plane. We kept the inclination 60^o. With the same inclination we designed two helical blades by changing the blade curvature. The blade curvature radii are 125 mm and 140 mm with 500 mm height. A helical blade of 140mm curvature radius is shown in Fig. 2.

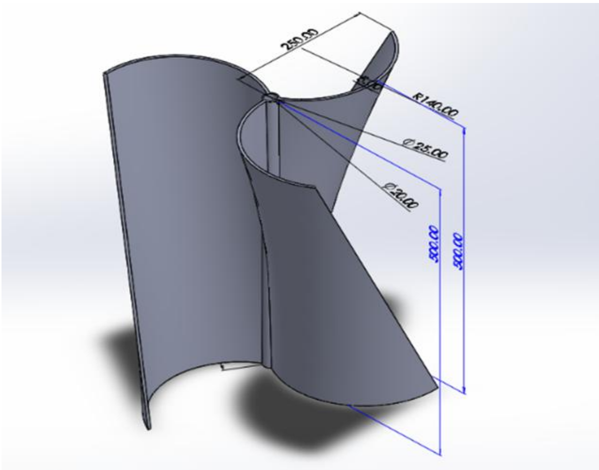

Fig. 2: Helical blade of 140mm curvature radius

3. Icewind Blade**:** Three types of Icewind blades were designed. The curvature radii were 250 mm, 280 mm with 500 mm height and 250 mm with 400 mm height. An icewind blade of 280mm curvature radius are shown in Fig. 3.

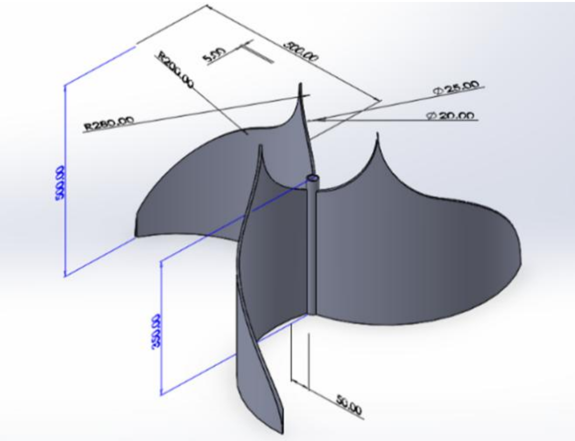

Fig.3 : Icewind blade of 280mm curvature radius

2.2 Generation of Mesh

The way computational fluid dynamics (CFD) programming works is by explaining fluid elements conditions around the geometry following the imperatives we indicated. So as to decide the focuses at which these conditions will be fathomed a mesh is produced. The mesh discretizes the physical space into a limited number of focuses. The higher the quantity of focuses (for example the work size) the more exact the arrangement and the additional time and power it will take to unravel. An example of a mesh is given later. Mesh was done with ANSYS 16.0 (student version). All the designs were meshed with zero relevance. The relevance center was taken fine and smoothing was high. The meshed part is shown below:

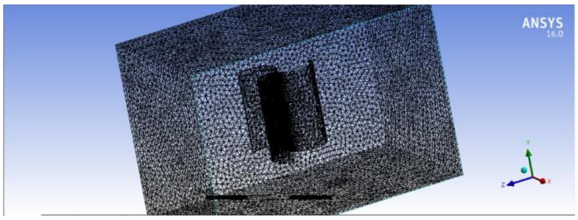

Fig. 4: Mesh of barrel blade (R125mm, H500mm)

2.3 Mathematical Modeling and Data Reduction

2.3.1 Governing Equation

In fluid dynamics there are three governing equations. These are momentum, continuity and energy equation. Since vehicle travels relatively low speed, Ma<0.3 and constant temperature the flow can be assumed incompressible and isothermal, the energy equation can then be neglected.

Conservation of Mass- The Continuity Equation [10]

$$\frac{\partial \rho}{\partial t}+\frac{\partial(\rho u)}{\partial x}+\frac{\partial(\rho v)}{\partial y}+\frac{\partial(\rho w)}{\partial z}=0 \qquad (2)$$

As the flow is approximated as incompressible, density is not a function of time or space. Thus $\frac{\partial u}{\partial t} \cong 0$. So we can write the above equation as-

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}=0 \qquad (3)$$

Conservation of Linear Momentum- Navier-Stokes Equation [11]

The x-component of the momentum equation as-

$$\rho\frac{Du}{Dt}= -\frac{\partial P}{\partial x}+\rho g_x+\mu\nabla^2 u$$
(4)

In similar fashion, we write the y-and z-components of the momentum equation as-

$$\rho\frac{Dv}{Dt}= -\frac{\partial P}{\partial y}+\rho y+\mu\nabla^2 v$$
(5)

$$\rho\frac{Dw}{Dt}= -\frac{\partial P}{\partial z}+\rho g_z+\mu\nabla^2 w$$
(6)

Hence the equation of lift and drag force co-efficient are-

Drag co-efficient, $C_D = \frac{F_D}{\frac{1}{2}\rho V^2 A}$ Lift co-efficient, $C_L = \frac{F_L}{\frac{1}{2}\rho V^2 A}$

Basically, three governing equations are available. Since vehicles and other mechanical components run at low speed so here conservation of energy equation is neglected.

2.3.2 Turbulence Model

Standard k-ε model is the most widely-used engineering turbulence model which is robust and reasonably accurate. It is a semi-empirical model based on transport equations for turbulence kinetic energy and turbulent dissipation rate. Transport equation of k is derived from the exact equation, while the transport equation for ε is derived using physical reasoning. Standard k-ε model is valid only for fully developed turbulent flows. Enhanced wall function was used as ε equation contains a term which cannot be calculated without wall function.

Transport equation for turbulent kinetic energy (k) is as,

$$\frac{\partial(\rho k)}{\partial t}+\frac{\partial(\rho k u_i)}{\partial x_i}=\frac{\partial}{\partial x_j}\left[\left(\mu+\frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right]+G_k+G_b-\rho\varepsilon- Y_M+S_k \qquad (7)$$

And transport equation for turbulent dissipation rate (ε) is as,

$$\frac{\partial(\rho \varepsilon)}{\partial t}+\frac{\partial(\rho \varepsilon u_i)}{\partial x_i}=\frac{\partial}{\partial x_j}\left[\left(\mu+\frac{\mu_t}{\sigma_\varepsilon}\right)\frac{\partial \varepsilon}{\partial x_j}\right]+C_{1\varepsilon}\frac{\varepsilon}{k}(G_k+ C_{3\varepsilon}G_b)-C_{2\varepsilon}\rho\frac{\varepsilon^2}{k}+S_\varepsilon \qquad (8)$$

Where, μ_t = Turbulent viscosity $=\rho C_\mu\frac{k^2}{\varepsilon}$ (9)

G_k = Generation of the turbulent kinetic energy due to the mean velocity gradient

σ_k = Effective Prandtl number for turbulent kinetic energy

σ_ε = Effective Prandtl number for rate of dissipation

$C_{1\varepsilon}, C_{2\varepsilon}$ are constants

Model Constants:
The default values of model constants $C_{1\varepsilon}, C_{2\varepsilon}, C_\mu, \sigma_k, and\ \sigma_\varepsilon$ determined from experiments for fundamental turbulent flows and have the following values
$C_{1\varepsilon} = 1.44, C_{2\varepsilon} = 1.92, C_\mu = 0.09, \sigma_k = 1.0, \sigma_\varepsilon = 1.3$

2.4 Boundary Conditions

When the mesh was created, we determined the arrangement for Fluent. This part included the most subtleties, as it required numerous factors (models, solver, introductory values, number of steps, limit conditions). When the solver arrangement was done, the arrangement was found and was imagined in the results tab.
The simulation model was viscous- k epsilon. Navier-stokes equation was used to solve the problems. Number of iteration was firstly taken 100 and further calculation was done to reach convergence.
Boundary conditions that were applied are as follows:

- The fluid will be assumed as incompressible.
- Fluid type: Air.
- Test object Material: Aluminium
- Temperature: 298 K.
- Velocity for air: 5 m/s.
- Air density: 1.225 kg/m^3.

These boundary conditions are applied when doing the simulation. Then we followed the energy and momentum conservation equation in the simulation.
We run the solver for 100 iterations or until the solution converges. Because of the very high number of nodes in a 3D mesh (around 180 000 nodes), it takes up to 5 hours on 100% computing power to run one of these simulations.

3. RESULTS AND DISCUSSION

3.1 Data Collection and Analysis

After finding out the values of all variables they are collected and given below in the table:

Table 1: Values of different blades

Blade Design	**Height, H (m)**	**Curvature Radius, R (m)**	**Angle, θ (°)**	**Pressure drop, dP (Pa)**	**Torque, T (Nm)**	**Reference values of pressure***
Barrel Blade	0.5	0.125	0	20.77	0.462	19.81 (at 30°) 17.15 (at 90°)
	0.5	0.125	60	18	0.779	
	0.5	0.125	120	21.20	0.694	
	0.5	0.14	60	14.20	0.445	
Helical Blade	0.5	0.125	0	22.31	0.57	
	0.5	0.125	60	20.5	0.823	
	0.5	0.125	120	21.92	0.79	
	0.5	0.14	60	14.51	0.419	
Icewind Blade	0.5	0.25	0	25	0.642	18.02 (at 30°) 11.0 (at 90°)
	0.5	0.25	60	22.8	1.127	
	0.5	0.25	120	24.95	1.2	
	0.5	0.28	0	17.85	0.502	
	0.4	0.25	0	18.51	0.374	

*Note: the reference values were taken from a research paper in which the height of blade was 400mm and curvature radius was 200mm for icewind blades [12].

The data table shows pressure drop and momentum of blades at various tip angle (0°, 60°, 120°). The design which has maximum pressure drop and maximum momentum, that will produce more power than other designs at same condition and inlet parameters. That denotes the design will be more efficient than others. From the data table we found out that 0.5m height and 0.125m curvature radius is best of all barrel and helical design we have done as it has maximum pressure drop at the same inlet conditions of other design. In case of icewind blade, height 500mm and curvature radius 250mm gives best performance.

3.2 Pressure Drop and Torque

Various pressure drop and torque were found for three blades at different tip angle. They were plotted in graphs below:

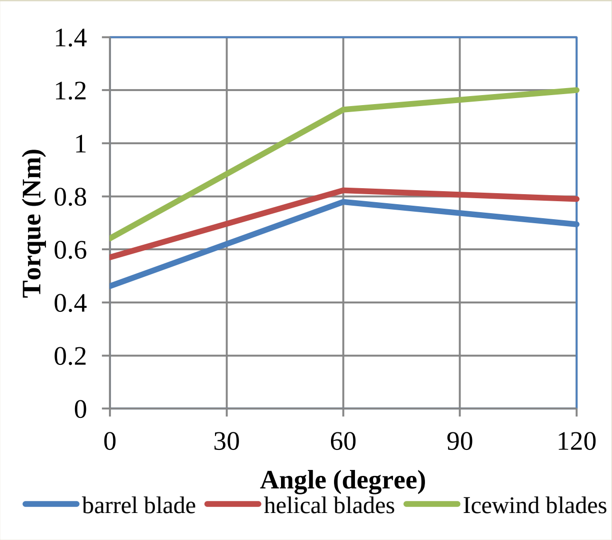

Fig. 5: Torque of blades at different tip angle

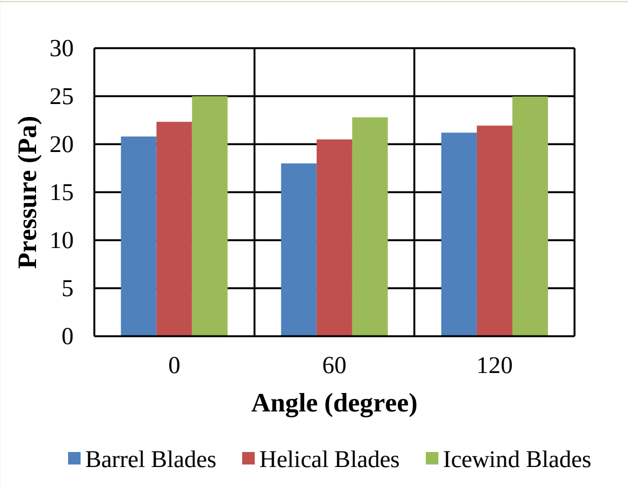

Fig. 6: Pressure difference of blades at different tip angle

From the above graph, it is very clear that icewind blade is the best of those three designs.

An icewind blade should be of 0.5 m height and 0.250 m curvature radius for 5m/s inlet air velocity. To calculate the power output,

Power, P = T× (V/H) watt

For Barrel blade, highest torque, T = .779 Nm, H = 0.5 m.

So, P = 7.79w

For helical blade, highest torque, T = .823Nm, H = 0.5 m.

So, P = 8.23w

For icewind blade, highest torque, T = 1.2, H = 0.5 m.

So, P = 12w

Icewind blade gives the highest torque.

In order to get maximum power output at 5m/s wind velocity and 0 degree tip angle, the icewind blade should be used which need to be of 500 mm height and 250 mm curvature radius.

3.3 Pressure Profiles of Different Blades

After iteration was done, pressure profile found out for every calculation. Some profiles are given below as example:

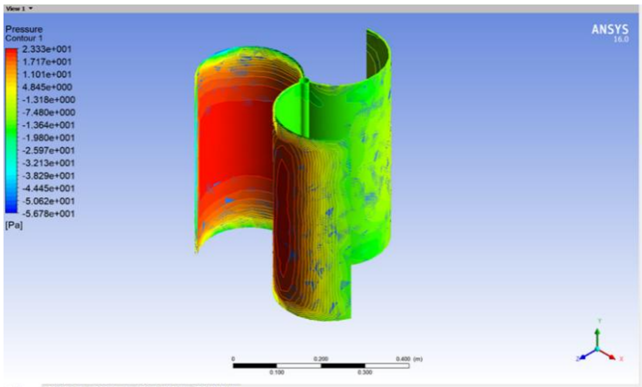

Fig. 7: Pressure profile of barrel blade(R125mm) at 0° tip angle

Figure 7 shows the pressure profile at 0° tip angle of a barrel blade which has 500mm height and 125mm curvature radius. Pressure falls from $2.333e^{+001}$ to $-5.678e^{+001}$.

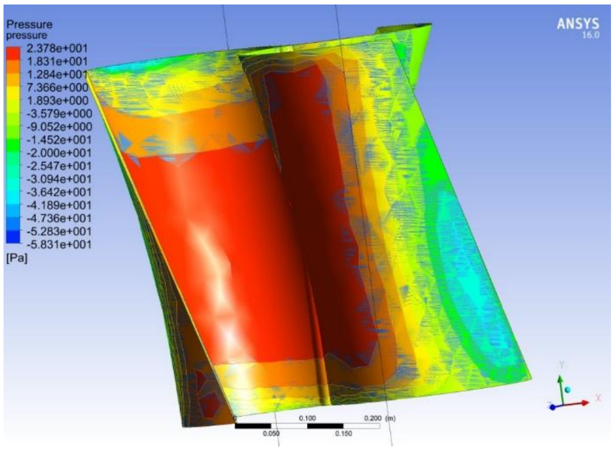

Fig. 8: Pressure profile of helical blade(R125mm) at 0° tip angle

Figure 8 shows the pressure contour at 0 degree tip angle of a helical blade of 500mm height and 125mm curvature radius. The pressure falls from $2.378e^{+001}$ to $-5.831e^{+001}$.

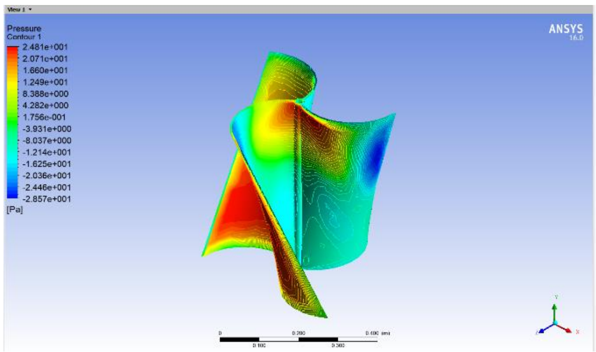

Fig. 9: Pressure profile of helical blade(R140mm) at 60° tip angle

Figure 9 shows the pressure profile at 60° tip angle of a helical blade of 500mm and 140mm curvature radius. Pressure range is 2.481e^{+001} to -2.875e^{+001}.

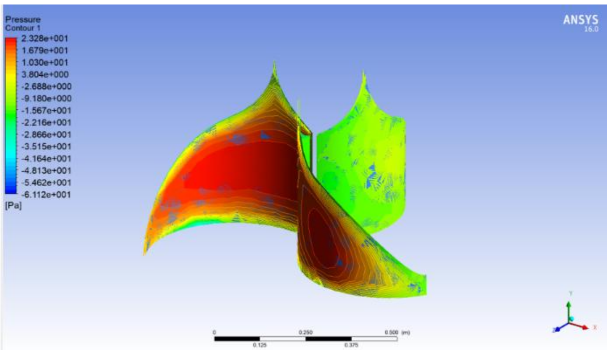

Fig. 10: Pressure profile of icewind blade(R250mm) at 0^{o} tip angle

Figure 10 shows pressure profile at 0^{o} tip angle of icewind blade of 500mm height and 250mm curvature radius. Pressure falls from 2.328e^{+001} to -6.112e^{+001}.

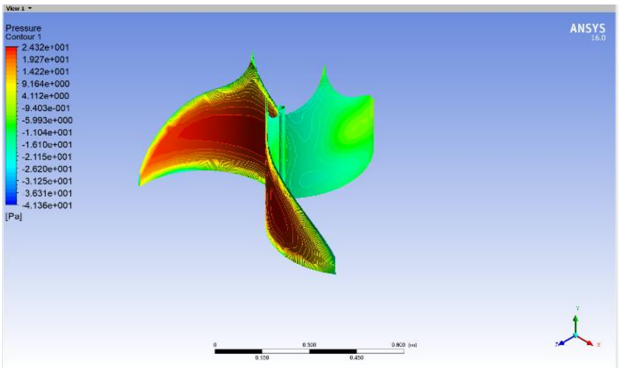

Fig. 11: Pressure profile of icewind blade(R280mm) at 0^{o} tip angle

Figure 11 shows the pressure profile at 0^{o} tip angle of icewind blade of 500mm height and 280mm curvature radius. Pressure falls from 2.432e^{+001} to -4.136e^{+001}.

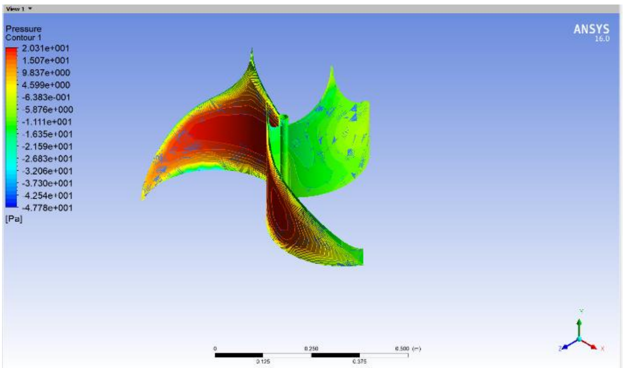

Fig. 12: Pressure profile of icewind blade(R250mm, H400mm) at 0^{o} tip angle

Figure 12 shows the pressure profile of icewind blade of 400mm height and 250mm curvature radius. Pressure falls from 2.031e^{+001} to -4.778e^{+001}.

4. CONCLUSION

As here in Bangladesh, the air speed is low, vertical axis wind turbine is more efficient than horizontal axis wind turbine as it can move at low speed. But, to increase the power output of a VAWT, a preferable design should be selected. So, we designed three types of blades and changed their parameters to find out optimum one design. It was observed that 500 mm height and 125 mm curvature radius is best of all barrel and helical design we have done for air velocity of 5 m/s. In case of icewind blade, height 500 mm and curvature radius 250 mm gives best performance. In case of simulation, tip angle plays a vital role to give the output results. Various tip angle gives various pressure drop and momentum values. Results showed that icewind blade creates more pressure and torque than two other blades. For future study, icewind turbine may be fabricated. But it may not give the same torque as we found after simulation. This is because, there is frictional losses and other drawbacks and system losses in a fabricated part.

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6. NOMENCLATURE

Symbol	Meaning	Unit
R	Curvature Radius	m
H	Height	m
dP	Pressure drop	Pa
T	Torque	Nm
V	Velocity	m/s
θ	Tip angle	degree