Design of Accelerated Wind Mill with Hollow Section of Blades

Elavarasan. E [*1], Hari Haran. R [1], Aravinthsamy. K[2], Jegan. T[3], Harish.V[4]
[*1]Assistant Professor, Department of Mechanical Engineering, Kongunadu College of Engineering and Technology
[1] Second year of Mechanical Engineering, Kongunadu College of Engineering and Technology
[2] Second year of Mechanical Engineering, Kongunadu College of Engineering and Technology
[3] Second year of Mechanical Engineering, Kongunadu College of Engineering and Technology
[4] Second year of Mechanical Engineering, Kongunadu College of Engineering and Technology

Abstract:- The wind energy is the one of the renewable energy which helps in extracting the current by making it to rotate. In our concept we had a design consideration that the slot is made in the wing where the impact of the air is more, in this the air is allowed is pass through the wing hollow section and make it to accelerate through the tip, so that the rotation of the blade will be more in order that it will produce more output. Advances in turbine blade design technology are required to make wind a viable large-scale producer of electricity. Blades need to become lighter, stronger, more efficient, and cheaper. This will allow turbines to withstand stronger wind, produce more power, and become economically competitive with coal or nuclear electricity production.

Our proposed concept of accelerated wind turbine comes under the category of upwind turbine. According to the statistical analysis of low speed winds around the area the power is theoretically calculated with the available data, three rotor horizontal axis wind turbine is constructed. The turbine blade is made up of light weight material supported with internal structure made up of light weight, high strength and with standing wind loads upto desired limit. The blade shape is of airfoil design (MH104).the selected airfoil design of the blade will have an altered design of MH104 on the upper chamber .on the upper chamber 20% of blade length from root, 1/4 of chord length from leading edge of the blade the hole in a rectangular arrangement on the upper chamber will allow the impact of air to flow into the blade from root to tip. Before the tip, at the trailing edge the flow is exhausted. This results in acceleration for the blade. Comparing to the normal blade configuration this proposed configuration will reduce the weight and also increases the mass flow rate of air flow on and inside the airfoil, also by the acceleration of air at the trailing edge of blade tip will improve the efficiency of the turbine.

Keywords:* *Anemometer, Betz's limit, HAWT, Martin Heppler Airfoils, and Yaw.

1. INTRODUCTION

1.1 Renewable Energy:

Renewable energy is energy which comes from natural resources such as sunlight, wind, rain, tides, and geothermal heat, which are renewable (naturally replenished). In 2008, about 19% of global final energy consumption came from renewable, with 13% coming from traditional biomass, which is mainly used for heating, and 3.2% from hydroelectricity. New renewable small hydro, modern biomass, wind, solar, geothermal, and bio fuels accounted for another 2.7% and are growing very rapidly. The share of renewable in electricity generation is around 18%, with 15% of global electricity coming from hydroelectricity and 3% from new renewable.

Wind power is growing at the rate of 30% annually, with a worldwide installed capacity of 158 giga watts (GW) in 2009, and is widely used in Europe, Asia, and the United States. At the end of 2009, cumulative global photovoltaic (PV) installations surpassed 21 GW and PV power stations are popular in Germany and Spain.

Renewable energy is derived from natural processes that are replenished constantly. In its various forms, it derives directly from the sun, or from heat generated deep within the earth. Included in the definition is electricity and heat generated from solar, wind, ocean, hydropower, biomass, geothermal resources, and bio fuels and hydrogen derived from renewable resources.

1.2 Wind Power:
Airflows can be used to run wind turbines. Modern wind turbines range from around 600 kW to 5 MW of rated power, although turbines with rated output of 1.5–3 MW have become the most common for commercial use; the power output of a turbine is a function of the cube of the wind speed, so as wind speed increases, power output increases dramatically. Areas where winds are stronger and more constant, such as offshore and high altitude sites, are preferred locations for wind farms.

1.3 Wind Turbine:
A wind turbine is a device that converts kinetic energy from the wind into mechanical energy. If the mechanical energy is used to produce electricity, the device may be called a wind generator or wind charger. If the mechanical energy is used to drive machinery, such as for grinding grain or pumping water, the device is called a windmill or wind pump. A wind turbine in which the axis of the rotor's rotation is parallel to the wind stream and the ground. All grid-connected commercial wind turbines today are built with a propeller-type rotor on a horizontal axis (i.e. a horizontal main shaft). Most horizontal axis turbines built today are two- or three-bladed, although some have fewer or more blades.

1.4 History:
Windmills were used in Persia (present-day Iran) as early as 200 B.C. The wind wheel of Heron of Alexandria marks one of the first known instances of wind powering a machine in history. However, the first known practical windmills were built in Sistan, a region between Afghanistan and Iran, from the 7th century. These "Panemone" were vertical axle windmills, which had long vertical drive shafts with rectangular blades. Made of six to twelve sails covered in reed matting or cloth material, these windmills were used to grind corn or draw up water, and were used in the grist milling and sugarcane industries. Windmills first appeared in Europe during the middle ages. The first historical records for their use in England date to the 11th or 12th centuries and there are reports of German crusaders taking their windmill-making skills to Syria around 1190. By the 14th century, Dutch windmills were in use to drain areas of the Rhine delta. A forerunner of modern horizontal-axis wind generators was in service at Yalta, USSR in 1931. This was a 100 kW generator on a 30-metre (98 ft) tower, connected to the local 6.3 kV distribution system. It was reported to have an annual capacity factor of 32 per cent, not much different from current wind machines. In the fall of 1941, the first megawatt-class wind turbine was synchronized to a utility grid in Vermont.

1.5 Types:
The three primary types:
VAWT Savonius,
HAWT towered,
VAWT Darrieus as they appear in operation.

1.6 Horizontal Axis:
Horizontal-axis wind turbines (HAWT) have the main rotor shaft and electrical generator at the top of a tower, and must be pointed into 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. Since a tower produces turbulence behind it, the turbine is usually positioned upwind of its supporting tower. Since cyclical (that is repetitive) turbulence may lead to fatigue failures, most HAWTs are of of upwind design

1.7 Vertical-Axis Wind Turbines: VAWTs have the main rotor shaft arranged vertically. Key advantages of this arrangement are that the turbine does not need to be pointed into the wind to be effective. This is an advantage on sites where the wind direction is highly variable, for example when integrated into buildings. The key disadvantages include the low rotational speed with the consequential higher torque and hence higher cost of the drive train, the inherently lower power coefficient, the 360 degree rotation of the aerofoil within the wind flow during each cycle and hence the highly dynamic loading on the blade, the pulsating torque generated by some rotor designs on the drive train, and the difficulty of modeling the wind flow accurately and hence the challenges of analyzing and designing the rotor prior to fabricating a prototype

1.8 Components of HAWT:

Conventional horizontal axis turbines can be divided into three components.

1. The rotor component, which is approximately 20% of the wind turbine cost, includes the blades for converting wind energy to low speed rotational energy.
2. The generator component, which is approximately 34% of the wind turbine cost, includes the electrical generator, the control electronics, and most likely a gearbox (e.g. planetary gearbox, adjustable-speed drive or continuously variable transmission component for converting the low speed incoming rotation to high speed rotation suitable for generating electricity.
3. The structural support component, which is approximately 15% of the wind turbine cost, includes the tower and rotor yaw mechanism.

1.9 Wind Turbine Design Configuration and Blade Design:

1.9.1 Configurations:

There are two basic designs of wind turbines: the vertical-axis and the horizontal-axis. The horizontal-axis wind turbines have the rotor shaft and generator at the top of the tower. For the vertical-axis wind turbines, the rotor shaft is arranged vertically and the generator and gearbox is placed near the ground so that the tower does not need to support it. Three major types of turbine design are

1. Conceptual deign
2. Preliminary design
3. Detailed designs

1.9.2 Turbine size:

For a given survivable wind speed, the mass of a turbine is approximately proportional to the cube of its blade-length. Wind power intercepted by the turbine is proportional to the square of its blade-length. The maximum blade-length of a turbine is limited by both the strength and stiffness of its material. Labor and maintenance costs increase only gradually with increasing turbine size, so to minimize costs, wind farm turbines are basically limited by the strength of materials, and sitting requirements. Typical modern wind turbines have diameters of 40 to 90 meters (130 to 300 ft) and are rated between 500 kW and 2 MW. As of 2010 the most powerful turbine is rated at 7 MW.

1.9.3 Blade Designs:

The lift design employs the same principles that enable planes to fly. A wind speed and pressure differential is created between the upper and lower surfaces of the blade when air flows past it. The air sliding along the upper surface will move faster than the lower surface air. This causes the lower surface pressure to be greater than the upper surface. This creates the lift, which is perpendicular to the direction of the wind. When the blades are attached to a central axis, the lift causes a rotational motion. Lift design blades typically have high rotational speeds. Therefore, lift design blades are better for electricity generation than drag design blades. Wind turbines are designed to exploit the wind energy that exists at a location. Aerodynamic modeling is used to determine the optimum tower height, control systems, number of blades and blade shape.

1.9.4 Blade count:

The determination of the number of blades involves design considerations of aerodynamic efficiency, component costs, system reliability, and aesthetics. Noise emissions are affected by the location of the blades upwind or downwind of the tower and the speed of the rotor. Given that the noise emissions from the blades' trailing edges and tips vary by the 5th power of blade speed, a small increase in tip speed can make a large difference.

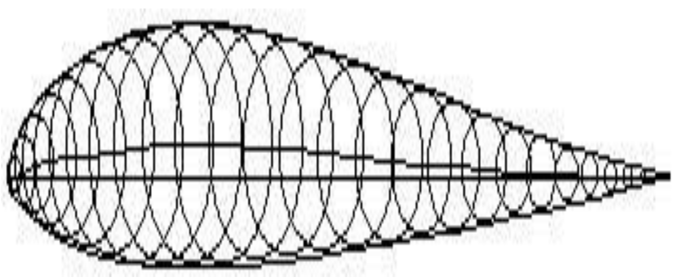
1.9.5 Blade materials:

Current manufacturing methods for blades in the 40 to 50 meter range involve various proven fiberglass composite fabrication techniques. Manufactures such as Nordex and GE Wind use an infusion process for blade manufacture. Other manufacturers use variations on this technique, some including carbon and wood with fiberglass in an epoxy matrix. Options also include prepreg fiberglass and vacuum-assisted resin transfer molding. Essentially each of these options are variations on the same theme: a glass-fiber reinforced polymer composite constructed through various means with differing complexity. Perhaps the largest issue with more simplistic, open-mold, wet systems are the emissions associated with the volatile organics released into the atmosphere. As turbine blades are approaching 60 meters and greater, infusion techniques are becoming more prevalent as the traditional resin transfer molding injection time is too long as compared to the resin set-up time, thus limiting laminate thickness. Carbon fiber-reinforced load-bearing spars have recently been identified as a cost-effective means for reducing weight and increasing stiffness. The use of carbon fibers in 60 meter turbine blades is estimated to result in a 38% reduction in total blade mass and a 14% decrease in cost as compared to a 100% fiberglass design.

2.1. SELECTION OF MAIN PARAMETERS:

2.1.1 Selection of Airfoil:

MH 104(Martin Hepperle)



Designed for the 40% radius station of stall controlled, horizontal axis windmills. MH 102, MH 104, MH 106, MH 108, MH 110,*.are some of the wind mill airfoils. The profile in co-ordinates is shown in figure 3.1*

Characteristics of MH104

1.Thickness: 15.3%

2.Moment coefficient of cm c/4 = +0.009.

3.Zero lift direction = -0.4º.

4.Maximum lift coefficient of Ca = 0.98.

5.Can be used at Reynolds numbers of 500'000 and above.

Calculated Polars (PROFIL/Eppler):

Coordinates in **XML format**

X	**Y**
1.00000000	0.00000000
0.99619582	0.00017047
0.98515158	0.00100213
0.96764209	0.00285474
1.00000000	0.00000000

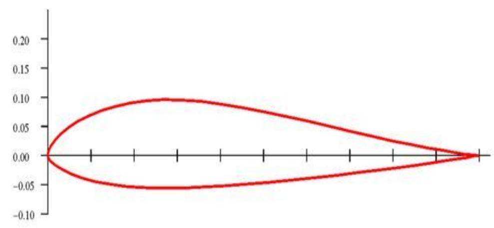


Figure 3.1 MH104 profile

2.1.2 Co-efficient of lift Vs Angle of attack:

The experimental data indicate that CL varies linearly with over a large range of angle of attack. Thin airfoil theory, which is the subject by more advanced books on aerodynamics, also predicts the same type of linear variation. The slope of the linear position of the lift curve is designed as lift slope there is still a positive value of CL that is there is still a positive value of CL that is, there is still some lift even when the airfoil is at zero angle of attack.

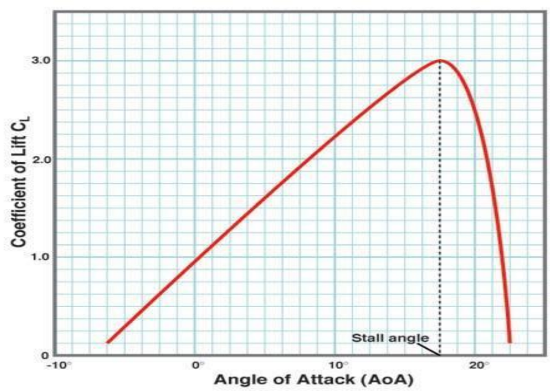


Figure 2.2 Co-efficient of lift Vs Angle of attack – graph

2.1.3 Co-Efficient Of Lift Vs Co-Efficient Of Drag:

The drag polar is a parabola with its axis on the zero-lift axis and its vortex is CD

$CD = CD0 + (CL^2/\rho\pi AR)$

CD0-is the parasite drag co-efficient at zero lift And $(CL^2/\rho\pi AR)$ includes both induced drag and the contribution to parasite drag due to lift in our redefined e, which now includes the effect from is called the Oswald efficiency factor. The basic aerodynamic properties of the airplane are $CD = CD0 + (CL^2/\rho\pi AR)$ and we consider both CDo and e as known aerodynamic qualities obtained from the aerodynamicist.

2.2 The Co-Efficient of Lift Vs Co-Efficient of Drag is shown in figure

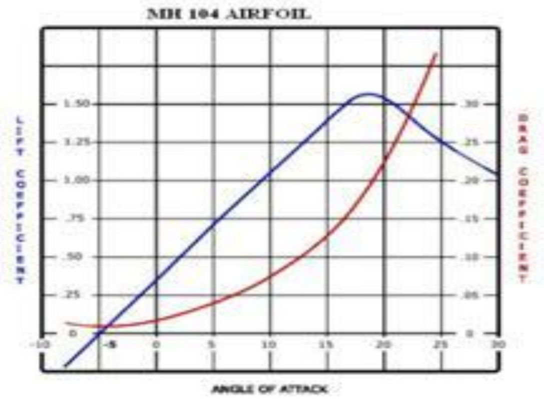


Figure 3.3 (Co-Efficient Of Lift Vs Co-Efficient Of Drag)

2.3 Coefficients of lift, CL and coefficient of drag, Cd:

Lift coefficient may be used to relate the total lift generated by an aircraft to the total area of the wing of the aircraft. In this application it is called the plan form lift coefficient CL

The lift coefficient CL is equal to:

$CL=L/((1/2)\rho V^2)=L/qA$

Where

1.L is the lift force,
2.ρ is fluid density,
3.V is true airspeed,
4. q is dynamic pressure, and A is planform area.

2.3.1 Reynolds Number:

Reynolds number can be defined for a number of different situations where a fluid is in relative motion to a surface. These definitions generally include the fluid properties of density and viscosity, plus a velocity and a characteristic length or characteristic dimension. This dimension is a matter of convention – for example a radius or diameters are equally valid for spheres or circles, but one is chosen by convention. For aircraft or ships, the length or width can be used. For flow in a pipe or a sphere moving in a fluid the internal diameter is generally used today. Other shapes have an equivalent diameter defined. For fluids of variable density (e.g. compressible gases) or variable viscosity (non-Newtonian fluids) special rules apply. The velocity may also be a matter of convention in some circumstances, notably stirred vessels.

Flow in Pipe

For flow in a pipe or tube, the Reynolds number is generally defined as:

$$RE = \rho VD\, \nu / \mu = VDH / \nu = QDH / VA$$

Where:

1.DH is the hydraulic diameter of the pipe (m).
2.Q is the volumetric flow rate (m^3/s)
3.A is the pipe cross-sectional area (m^2).

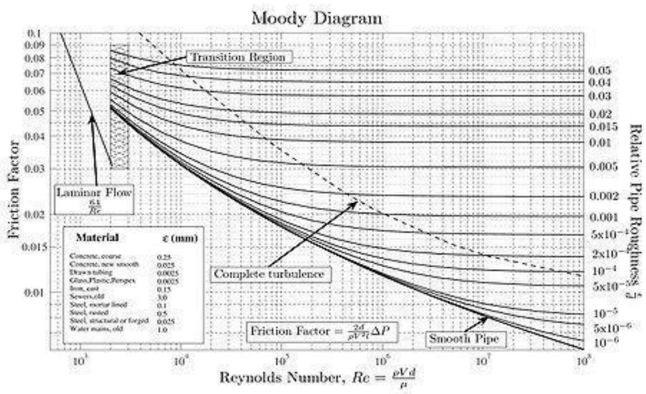
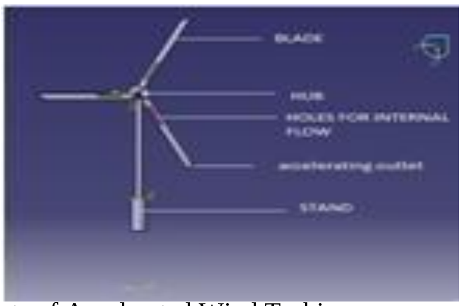


Figure 2.3 Moody diagram

Pressure drops seen for fully-developed flow of fluids through pipes can be predicted using the Moody diagram which plots the Darcy–Weisbach friction factor f against Reynolds number Re and relative roughness ε / D. The diagram clearly shows the laminar, transition, and turbulent flow regimes as Reynolds number increases. The nature of pipe flow is strongly dependent on whether the flow is laminar or turbulent.

3. MODELLING

Model of Accelerated Wind Turbine:



Components of Accelerated Wind Turbine:

- DC alternator
- Driver belts
- Blade
- Hub
- Tower, yaw mechanism.

3.1. DC alternator (Balmar high-output)

An alternator is an electromechanical device that converts mechanical energy to electrical energy in the form of alternating current.

Most alternators use a rotating magnetic field but linear alternators are occasionally used. In principle, any AC electrical generator can be called an alternator, but usually the word refers to small rotating machines driven by automotive and other internal combustion engines. Alternators in power stations driven by steam turbines are called turbo-alternators.

3.2. Driver belts

High-output Balmar alternator will increase horsepower load when compared to standard OEM alternator. This additional load may require that you replace the standard drive belt with a heavier-duty unit. Many belt manufacturers supply premium quality belts, designed specifically for heavy-duty marine and industrial applications. Among these are the Green Stripe belt by Gates and the Top Cog belt from Dayco. In addition, many auto parts suppliers, such as NAPA, carry extra heavy-duty belts designed to support larger horsepower loads.As well as belt quality, belt size can have a substantial impact on alternator performance. As a rule-of thumb, we recommend a minimum 3/8” belt (measured across the back of the belt) for our 80-amp alternators. Minimum belt width for 100 to 110- amp alternators is 1/2”. Any alternator larger than 110-amps will require dual belts for optimal performance and belt life. Should you find that your belt is undersized for your alternator, the Amp Manager mode, available in the Max Charge MC-612 (12-volt) and MC-624 (24-volt) multi-stage regulators, enables you limit the maximum field potential of the regulator and limit the horsepower load of the alternator.

3.3. Blade design:

The blades are basically the sails of the system; in their simplest form, they act as barriers to the wind (more modern blade designs go beyond the barrier method). When the wind forces the blades to move, it has transferred some of its energy to the rotor. The blade parameters that is used in our accelerated wind turbine concept is

No. of blades	= 3
Blade length	= 1 meter
Aerofoil selected	= MH 104
Chord length	= 150 mm
Chord thickness	= 30 mm
Pad length	= 40 cm
Accelerated outlet	= 10 mm
Blade balancing	= 120°

3.4. Blade hub

As the rotor diameters and rated capacities have increased, so has the hub height of the wind turbines. There is no standard hub height or ratio of hub height to rotor diameter. Wind resource characteristics, terrain, turbine size, availability of cranes, and visual impacts are but a few critical items that are used to determine the most optimum hub height for our project. Maximum tip heights (the highest point of the rotor) depend on the hub height and rotor diameter. The blade hub that we have selected for our accelerated wind turbine has Hub diameter = 70 cm

3.5. Tower

The tower is perhaps one of the most important parts of a wind turbine. It can also be well over half the cost of a system overall. A tower should be 10' above anything within a 300' radius in order to keep the turbine up in clean, non-turbulent wind. Our wind generator should be at least 10 feet above any obstructions within 300 feet.

4. CFD ANALYSIS

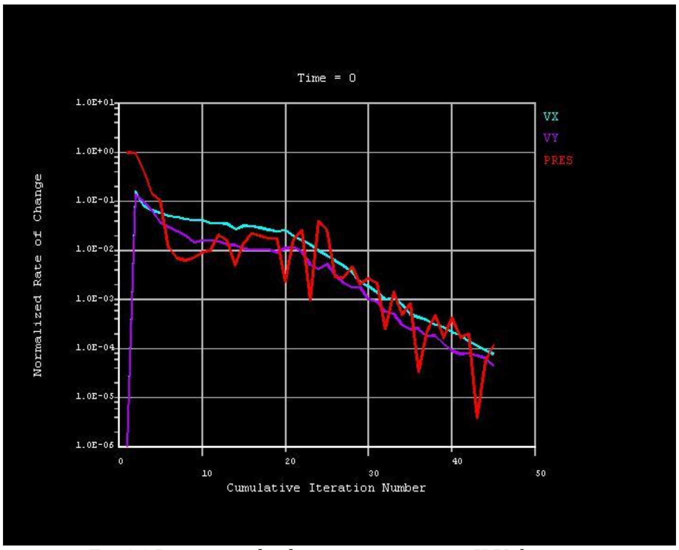


Fig.4.1.Pressure and velocity components in X Y direction

The Pressure and velocity components in X Y direction is analyzed using iteration methods (approximately 45 iterations) and the resulting graph is shown in figure 4.1

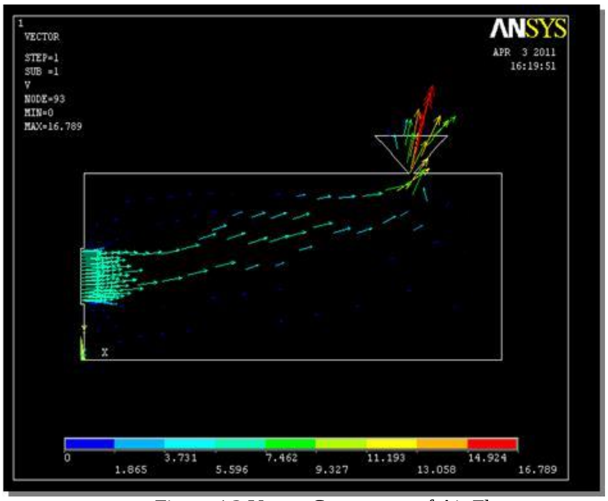


Figure 4.2 Vector Component of Air Flow

The air entering inside the hollow section of the blade is CFD analyzed using ANSYS and the result is shown in figure 4.2.

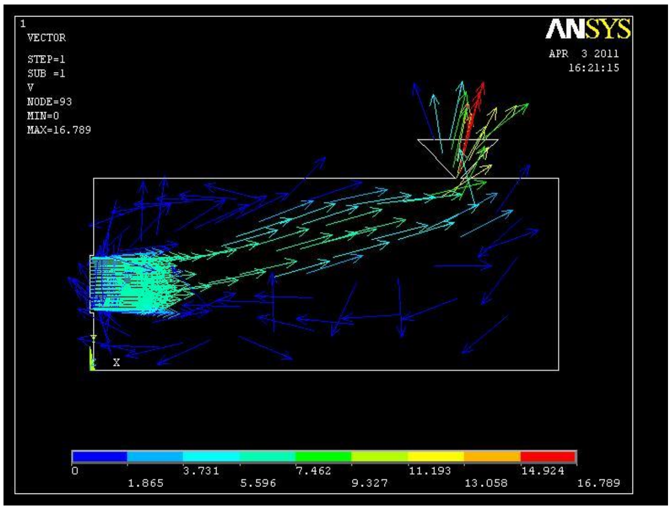


Figure 4.3 Magnitude component of flow in the hollow section of the blade.

The above figure 4.3 illustrates the magnitude component of the flow of atmospheric air inside the blade in a uniform condition. Also the deviation of air inside the area which is not tends to direction of flow.

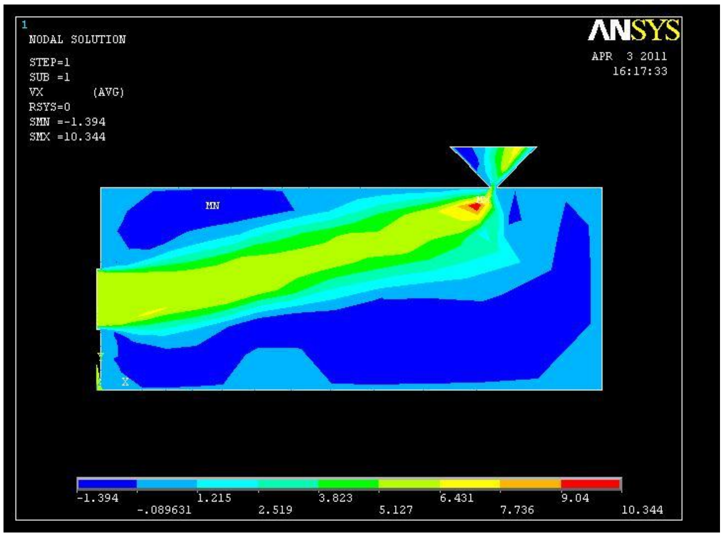


Figure 4.4 Flow of atmospheric air inside blade in X direction

The above figure 4.4 shows the analysis of air flow in y direction happened inside the blade. The flow starts after some deviation from the inlet.

ISSN: 2278-0181
ICITMSEE - 2018 Conference Proceedings

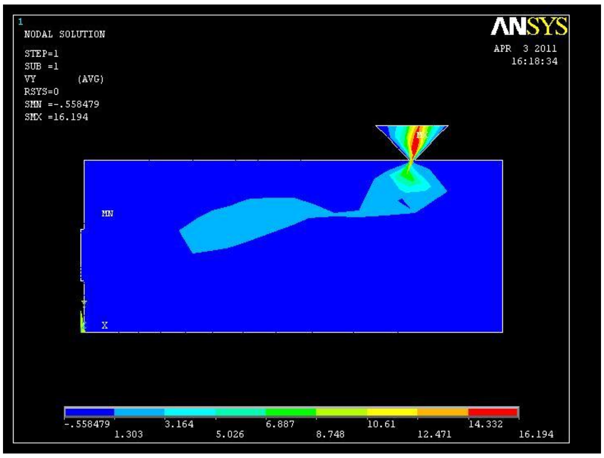


Figure 4.5 Flow of atmospheric air inside blade in Y direction

The above figure 4.5 shows the analysis of air flow in y direction happened inside the blade. The flow starts after some deviation from the inlet.

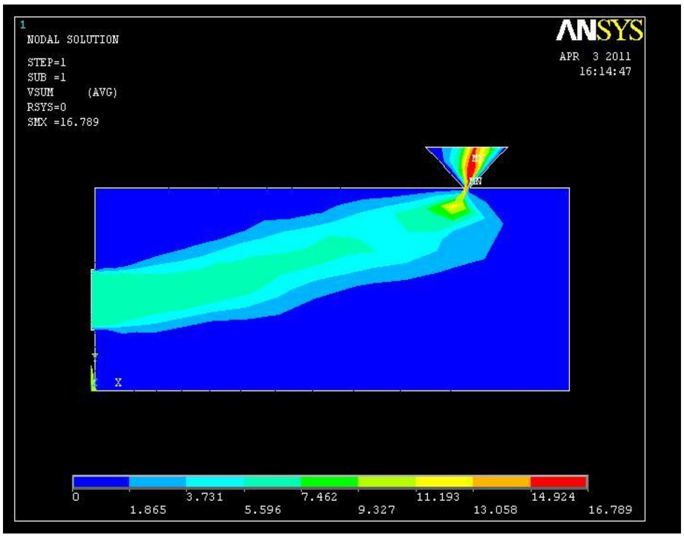


Figure 4.6 Acceleration of air at outlet with atmospheric air inlet.

5. PERFORMANCE CALCULATION

5.1. Determining the wind potential:

Before installing a wind turbine on a location the performance of any wind turbine depends solely on the wind that it encounters. The power available to a wind turbine is proportional to the cube of the wind speed thus small changes in wind speed have tremendous impacts on the power output.

Step #1: Install the anemometer as close as possible to the intended location of your wind turbine. Step #2: Collect actual wind data at our site

Step #3: Uninstall the anemometer **5.2**

Betz's Limit:

We have the power of a free-flowing wind stream, we turn to the question of how much power is extracted by our windmill in .To find the power extracted, we find the energy difference in the two sides of the windmill and take the derivative with respect to time. This gives us

$P = (\Delta E/\Delta T) = (1/2)[(dm/dt)(V1^2-V2^2)] = (1/2)\rho AV(V1^2-V2^2)$

This expression tells us the power extracted by our windmill. In the first step, we simply rewrote the energy difference on both sides of the mill. To find the dm/dt, we compute the mass passing by the windmill (of area A) per time. Note that we have reasonably assumed the density of the air is the same on both sides. At this point, it is useful to write v, the wind velocity directly at the windmill, in terms of v1 and v2. The naive guess would be that v=1/2(v1+v2), since the speed at the interface could reasonably be treated as the average of the speeds on either side. This means we end up with the extracted power where we define q as v2/v1. The ratio of the extracted power to the initial power in the column of undisturbed air.

$Pextr = (1/4)\rho A(V1+V2)(V1^2-V2^2)$

Plugging q=1/3 into the above equations, we find that the maximum efficiency Pextr/P0 is

$(Pextr/Po) = (1/2)(1+(1/3))(1-(1/3)^2 =$

$(16/27) = 59\ \%$

5.3 To determine the appropriate size of wind turbine:

Wind turbine size=consumption in kilowatt-hours (kWh)/ 12.

Assume consumption = 2000kwh, Then turbine size =2000/12=166.66kwh

To get a preliminary estimate of the performance of a particular wind turbine, the formula required is below:

AEO = 1.64 D^2 ^V3

1250=1.64*D^2 *5^3

D=2.5 m

So the Rotor diameter required for wind turbine will be 2.5 m

5.3.1 The power output of a wind generator is proportional to the cube of the wind speed – Suppose the wind speed is 5m/s then power output will be 5*5*5=125 watts

5.4 The power of wind:

Wind is made up of moving air molecules which have mass - though not a lot. Any moving object with mass carries kinetic energy in an amount which is given by the equation:

Kinetic Energy = 0.5 x Mass x Velocity^2

where the mass is measured in kg, the velocity in m/s, and the energy is given in joules. Air has a known density (around 1.23 kg/m^3 at sea level), so the mass of air hitting our wind turbine (which sweeps a known area) each second is given by the following equation:

Mass/sec (kg/s) = Velocity (m/s) x Area (m^2) x Density (kg/m^3)

Mass/sec (kg/s)=5*3.925*1.2

=2.413 (kg/s)

where Power is given in Watts (i.e. joules/second), the Swept area in square metres, the Air density in kilograms per cubic metre, and the Velocity in metres per second.

Power = 0.5 x 3.925 x 1.23 x 5^3

=603.46 watts.

5.5 Formula Governing Power-Output of an Ideal Windmill:

$$P = \frac{16}{27}\frac{\rho}{2}v_1^3 A$$

This is known as Betz's formula [3], and is the maximum theoretically allowed power output, using Betz's limit.

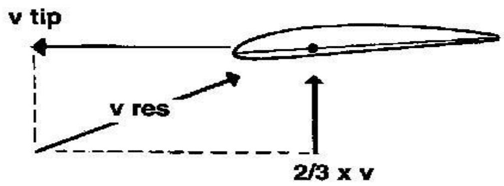
P=(16/27)*(1.23/2)*5^3*3.925

P=178.8watts (theoretically allowed power output).

5.6 Blade Design:

With this rather simple method we over the months have made very efficient blades (Cp-max measured = 0.46

5.6.1. Velocity calculation on rotor:



The wind speed "V" is slowed down in the rotor plane. Energy is extracted.

The wind speed after the rotor is apx. 1/3 x V (max. efficiency).

Wind speed before hitting on the blade is 5m/s Wind speed after hitting on the blade=1/3 x 5 =1.56m/s

5.7. Wind Shear Formula calculation:

The wind speed at a certain height above ground level is:

v = v ref ln(z/z 0)/ln(z ref /z 0)

v = wind speed at height z above ground level. v ref = reference speed, i.e. a wind speed we already know at height z ref .

ln(...) is the natural logarithm function. z = height above ground level for the desired velocity,

z 0 = roughness length in the current wind direction. z ref = reference height, i.e. the height where we know the exact wind speed v ref .

5.8. Turbine efficiency:

It is not possible to convert all of the wind's kinetic energy into mechanical energy. Some of the wind will either be deflected away right before reaching the rotor plane or carried away by the air that leaves the turbine; some energy has to be left in the wind. The "energy out" is the energy converted by the turbine blades into mechanical energy, plus whatever energy is left in the air after it passes through the turbine rotors.

High efficiency 3-blade-turbines have tip speed ratios of 6-7. The tip speed ratio will determine how fast the wind turbine will want to turn and so has implications for the alternator that can be used.

CONCLUSION

An experimental investigation of the air flow inside the hollow airfoil is modeled and analysed and the fabrication of the accelerated wind turbine is successfully done. By this proposed idea the efficiency of the wind turbine can be increased by the influence of air flow through the hallow section and acceleration at tip. The available wind energy can be utilized upto Betz's limit by optimized design in every aspects like 1.Obstacle less for wind flow
2.Tower height
3.Mass flow rate during climatic changes
4.Airfoil design
5.Losses due to turbulence inside the blade ,skin friction on the surface can be reduced
6.Turbine location.
7.Comparison results are based on the aerodynamic characteristic measurements

Thus by our design configuration on MH104 airfoil hopes to give increased performance over ordinary MH104 airfoil. The acceleration by the airflow exhausting through the slotted tip in the trailing edge near blade tip will increase rpm of the blade and also helps in increasing the axial force.

REFERENCES

1.T.Suzuki, H. Okitsu. "Characteristics of Savonius Windmill Power System with a Synchronous Generator." Wind Engineering 6, 131 (1982).
2.M.Ragheb, "Theory of Wind Machines, Betz Equation" http://netfiles.uiuc.edu/mragheb, 2007.
3.M.Jischke, "On the Aerodynamics of Windmill Blades," Proc. Okla. Acad. Sci. 56 121 (1976).
4.Z.Salameh. "Optimum Windmill-Site Matching," IEEE Trans. Energ. Conv. 7, No. 4, 1992.
5.Gijs A.M. van Kuik The Lanchester – Betz–Joukowsky Limit. Wind Energy (2007), Volume 10, pp. 289-291
5.Leishman, J. Principles of Helicopter Aerodynamics, 2nd ed.. Cambridge University Press, 2006. p. 751.
6.Cottet, G-H. and Koumoutsakos, P. Vortex Methods. Cambridge University Press, 2000.
7.Leishman, J. Principles of Helicopter Aerodynamics, 2nd ed.. Cambridge University Press, 2006. p. 753.
8.Cottet, G-H. and Koumoutsakos, P. Vortex Methods. Cambridge University Press, 2000. p. 172.
9.Adkins and R. Liebeck. "Design of Optimum Propellers," J. Propul. Pwr, 10, No. 5, Sept 1994.
10.M. Ragheb, "Energy and Power Content of the Wind" http://netfiles.uiuc.edu/mragheb, 2007.