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DESIGN AND MANUFACTURING OF COST EFFICIENT HORIZONTAL AXIS WIND TURBINE

Hemant Pathade, Ketan Deshpande, Yogesh Nawale, Sagar Damare, Sanket Ambre

Department of Production Engineering, Amrutvahini College of Engineering (University of Pune),Sangamner, Dist. Ahmednagar, Maharashtra, India

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ABSTRACT

Wind energy and solar energy are the types of renewable energy which widely used in the world. Wind is the most available clean energy in the form of renewable energy. In current scenario, the horizontal and vertical axis wind turbine is the recent trend for power generation and energy utilization. But the cost of the HAWT & VAWT is high due to the cost of blades. Generally, blades are made up of carbon fibers and balsa wood. These are too much expensive materials. To overcome this problem we found the alternative material for carbon fibers. We use polymer composites & glass fiber composite as an alternative to carbon fibers. Once the die manufactured; the blades can be manufactured easily. The blades of this composite materials results in less cost and ease of manufacturing of the windmill. Hence we can provide green energy to the world in affordable cost. This cost effective wind turbine can be used in Remote areas, Farm-houses, Schools, Colleges, Banks etc.

We have successfully manufactured the HAWT which generates 1KW power within sixty thousand rupees. Hence we can provide green energy to the world in affordable cost.

Keywords: *Wind energy, HAWT, Polymer composite and Glass fiber blades, Green energy in affordable cost, Ease in Manufacturing.*

1. INTRODUCTION

Until end of 2011, it was reported by the World Wind Energy Association, that there are over 238,351 MW of wind power capacity in the world; The same wind power advocacy group stated that wind power now has the capacity to generate 500 TWh annually, which equates to about 3% of worldwide electricity usage. According to BTM Consult, a company that specializes in independent wind-industry research, the level of annual installed capacity has grown at an average rate of 27.8% per year for the past five years. These statistics demonstrate that wind energy is already a vital source of energy production around the globe and that the demand for wind energy solutions is increasing. [2] From an environmental standpoint, a wind farm is much preferred to a coal burning plant because of carbon emissions and other factors, but both methods of power generation require the consumer buy this power from a utility company. This project is aimed at determining how efficient the small wind turbine can be given the space constraints of a residential area. [1] The orientation of the shaft and rotational axis determines the first classification of the wind turbine.

A turbine with a shaft mounted horizontally parallel to the ground is known as a horizontal axis wind turbine or (HAWT). [1]

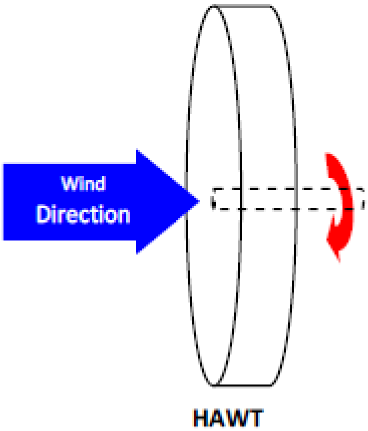


Fig.1.1 Working principle of HAWT [3]

After detailed study of Horizontal axis wind turbines which are available in market, many Research gaps were found such as the cost of conventional windmill blade is too high because of use of carbon fibre composites. Also the method of manufacturing such windmills is also too much complicated. To overcome those problem, this research is carried out.

Working of HAWT is shown in the following image. Due to the flow of the wind the blades and rotor rotates which simultaneously results in the rotation of shaft of Permanent Magnet Alternator and it generates electrical power.

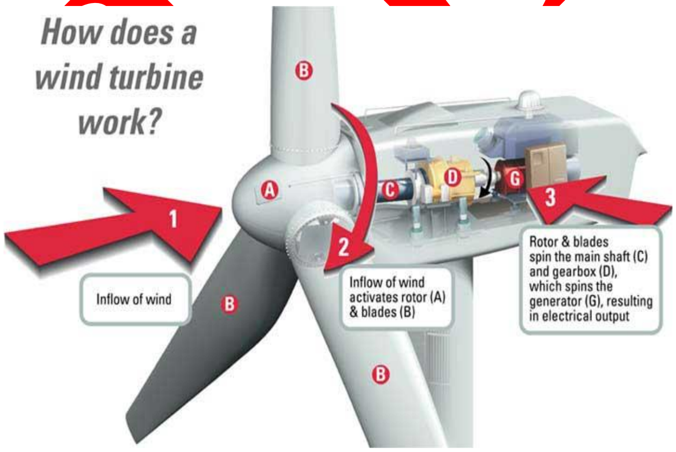


Fig1.2. Component of windmill system.[6]

2. PARTS DESIGN, CALCULATIONS AND METHODOLOGY

2.1. Hub

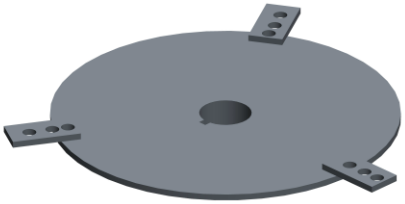


Fig.2.1 3D view of HAWT hub

The hub is the fixture for attaching the blades to the rotor shaft. It usually consists of nodular cast iron components for distribution of the blade loads to the wind support structure, i.e. ultimately to the tower. A major reason for using cast iron is the complex shape of the hub, which makes it hard to produce in any other way. In addition hereto, it must be highly resistant to metal fatigue. Thus, any welded hub structure is regarded as less feasible [9]. For designing the hub for loading the following consideration are used,

The loads at the blade-hub interfaces to be considered at the blade root for design of the hub consist of the following:

- full flapping moment
- flapping shear, resulting thrust on one blade
- lead-lag moment, power torque of one blade, and gravity loads
- lead-lag shear, in-plane force that produces power torque
- centrifugal forces
- pitching moments of one blade

Design loads can be calculated from the blade loads in accordance with this list.

The moments and forces transmitted to the hub and tower depend on the type of hub.

There are three types of hub:

i. Hinge less rigid hub, has cantilevered blades and transmits all moments to the tower.
ii. Teetering rotor hub, has two rigidly connected blades supported by a teeter pin joint, which can only transmit in plane moments to the hub. Flap wise moments are not transmitted.
iii. Articulated hub, has free hinges in flapping and lead-lag, so there is no mechanical restraint moment on the blades in either flapping or lead-lag. The hinge less hub is the most common configuration for wind turbine hubs.

Material used for Hub : Spheroidal graphite cast iron, also known as nodular cast iron, is the preferred material for the hub. Cast iron is classified according to its mechanical properties, such as strength and hardness, in EN1563. Cast hubs are usually tested by non-destructive testing (NDT) for verification of the mechanical properties and for detection of possible defects and internal discontinuities.(8)

2.2 Blade

It is the main part of the wind mill. The rotation of the wind turbine is done by the blade. The blades are rotated by the flow of wind. The shape and size of the blade is given by the different aerodynamic considerations. The fig shows the different parts of the blade.

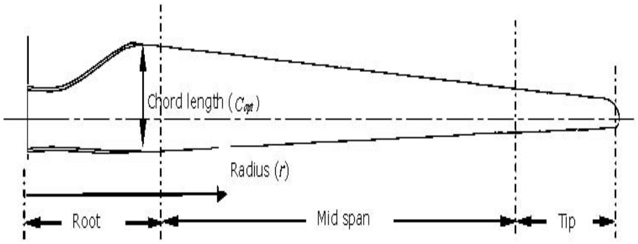


Fig.2.2 Terminology of the windmill blade

Overview of Aerodynamic Principals

Wind turbines are machines that remove energy from the wind by leveraging the aerodynamic principals of lift and drag. Lift and drag forces move the turbine blades which convert kinetic wind energy to rotational energy. The rotational energy can then be transformed into electrical energy. The rate of energy extracted from the wind is governed by Equation (1), where P is the power, T is the torque, and ω is the angular velocity of the turbine blades.

$$P = T * w \ldots\ldots (1)$$

Lift and drag forces are measured experimentally in a wind tunnel for airfoils as a function of the angle of attack, α. The angle of attack is defined as the angle between the chord line c of the airfoil and the direction of the wind. For aircraft wing design, it is generally ideal to choose the airfoil that has the greatest lift-to-drag ratio, since there will be the least amount of thrust required to maintain altitude. The objective of turbine blade design is also to maximize the lift force on the blade and reduce drag so that the force on the blade that acts in the tangential direction is maximized. Lift acts in the direction normal to the fluid flow, which is not necessarily acting in the tangential direction once the turbine blades begin to spin. In most wind turbine designs, only the lift force on a blade creates a tangential force in the correct direction, while the drag force creates a small tangential force in the opposite direction. Other than the tangential force, another force, called thrust, is also comprised of lift and drag and acts normal to the plane of rotation. In air turbine design, it is crucial to reduce the thrust on the turbine blades because it wastes energy and it requires a stronger blade to withstand its loading.

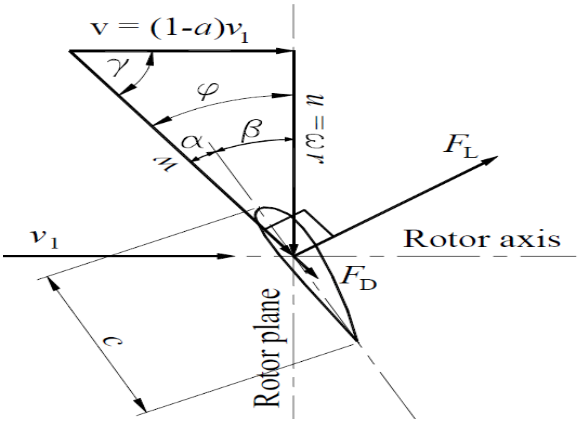


Fig.2.3 Forces and angles on the blade. [1]

$Fl = 0.5 * Cl * \varrho * w^2 * (bc) * B$…………..(i)

$Fd = 0.5 * Cd * \varrho * w^2 * (bc) * B$…………(ii)

Figure shows how the lift and drag forces are transformed into torque T and thrust T_h forces, which are required to determine the power created by the turbine[1].

Selection of airfoil

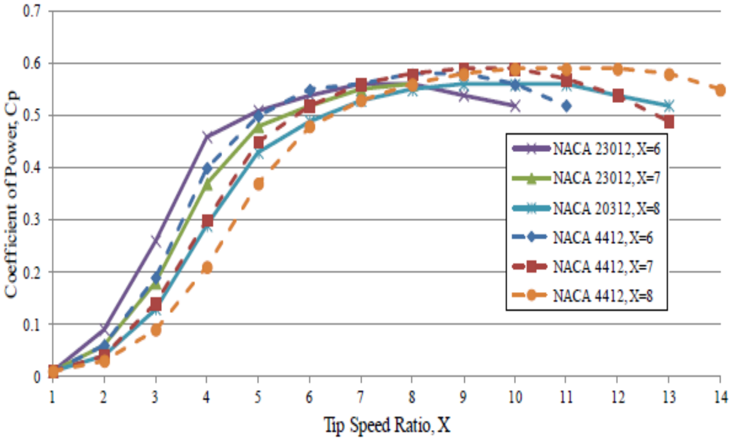
The airfoil is another parameter that can be varied to optimize a blade design. Associated with the variation in airfoil is the change in optimal coefficient of lift and optimal angle of attack. While the airfoil changes the blade cross section, it also alters the optimal coefficient of lift and optimal angle of attack, which affects the pitch and chord length distributions. There are mainly two types of airfoil are used in manufacturing of wind turbine. This are as follows,

i. NACA 23012
ii. NACA 4412.

The comparison between this two airfoils is given below,

The NACA 4412 airfoil is different than the NACA 23012 in that the maximum glide ratio occurs at an angle of attack of 6 degrees, not 7 degrees like the NACA 23012. Another difference between the two that will reshape the blade is the coefficient of lift at the maximum glide ratio. The corresponding coefficient of lift for the NACA 4412 is about 1.05 instead of 0.88.

The coefficient of power as output from the BEM spreadsheet will be compared between the results of the NACA 23012 and NACA 4412 airfoils. Three different blades were compared for each airfoil: the blades optimized for tip speed ratios of 6, 7, and 8. Figure shows the results of the comparison. For the range of tip speed ratios between 1 and 7, the NACA 23012 airfoil is notably more efficient for all three blades. For the blades optimized at a tip speed ratio of 8, while experiencing a tip speed ratio of 4, the NACA 23012 has a higher coefficient of power by almost 0.1. At a tip speed ratio of 7, the airfoils have almost identical performance, but for all speed ratios greater than 7, NACA 4412 out-performs the NACA 23012. The improvement in performance for the NACA 4412 increases with those blades optimized for greater speed ratios.



Graph 2.4 comparison between NACA23012 and NACA 4412.[1]

Both airfoils seem to have beneficial characteristics that are highly dependent on the tip speed ratio which they encounter. However, since the ratios greater than 7 have the 35 highest coefficient of power, it is apparent that the NACA 4412 airfoil is the more desirable of the two. The only detriment of the NACA 4412 airfoil is that if the ratio reduces to 6 or less, there is more of an abrupt decrease in efficiency than with the NACA 23012.So, we use the NACA 23012 for obtaining the better efficiency and high power output.[1]

Material of blade

Wind turbine blades are made of lightweight materials to minimise the loads from rotating mass. Mostly the blades are made up of two materials,

i. Carbone fibres
ii. Balsa wood

Glass and carbon fibres come in different types having different chemical compositions. The most important type of glass is E-glass. The mechanical properties, modulus and tensile strength, may vary significantly between different types of fibres and can also vary considerably within each type of fibre. There are for example low, medium and high strength carbon fibres. The selection and qualification of fibres is part of the blade design.

Wood core materials include balsa, conventional wood and plywood. Balsa is by far the most commonly used and is supplied in different densities, stiffness and strength increasing with density. Several species of wood can be used for wind turbine blades. Wood is applied as plywood or in lamellas to minimize the impact of imperfections like knots on the strength. It is important for the resistance of the wood that the water content is low. A high water content will result in low mechanical values, rot and fungus. The humidity shall be controlled during storage and manufacturing. Coating and sealing shall be qualified as part of design to govern the long-term water content in the wood.[9]

But the main problem related to this materials are that they have high cost and imported from other countries in India. So to overcomes this problem we find the alternative materials for this which gives the same properties in low cost.

The following factors to be considered while selecting the materials,

- Strength,
- Stiffness,
- Rigidity,
- Outdoor life,
- Light weight. [11]

Alternative materials

The selection criteria for selecting materials are gives above, according to that following material are selected,

I. Polypropylene,[7]
II. Glass Fibres.[10]

Pitch angle β, chord length c, and optimal angle Ø

Figure shows the velocities and the angles in a given distance, *r*, from the rotor axis. The rotor shown on the figure is with two blades, i.e. $B = 2$. To design the rotor we have to define the pitch angle β and the chord length c. Both of them depend on the given radius, that we are looking at therefore we sometimes write $\beta(r)$ and $c(r)$.

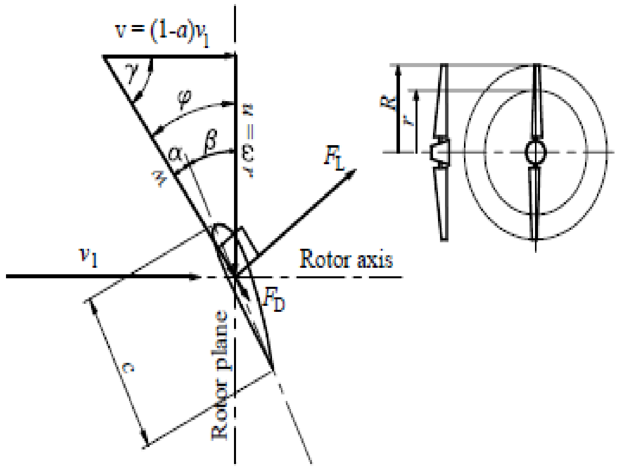


Fig.2.5 velocities and angles [2]

Angles, that all depends on the given radius

- $\gamma(r)$ = angle of relative wind to rotor axis
- $\varphi(r)$ = angle of relative wind to rotor plane
- $\beta(r)$ = pitch angle of the blade

Pitch angle: The blade, as shown on the figure is moving up wards, thus the wind speed, seen from the blade, is moving down wards with a speed of u.

We have,

$$w_2 = v_2 + u_2 \quad \ldots\ldots.(4.1)$$

But it does not include rotation of the wind,

Therefore

$$u = \omega * r\ (1) \qquad [m/s] \quad \ldots\ldots(4.2)$$

Here ω is the angular speed of the rotor given by,

$$\omega = 2\pi\ n\ (1) \qquad [rad/s] \quad \ldots\ (4.3)$$

where, *n* is the rotational speed of the rotor in round per second.

Now we define the "tip speed ratio" i.e.

$$X = \frac{wR}{v1} \quad \ldots\ldots\ldots.\ (4.4)$$

Combining these equations we get,

$$\gamma(r) = arc\ \tan\left(\frac{3rX}{2R}\right) \quad \ldots..\ [Rad]$$

Or

$$\varphi(\mathrm{r}) = \arctan\left(\frac{2R}{3rX}\right) \quad \ldots. \ [\mathrm{Rad}]$$

And then the pitch angle

$$\beta(r) = \arctan\frac{2R}{3rX} - \alpha_{\mathrm{d}} \quad \ldots\ldots.. \ [\mathrm{Rad}]$$

where α is the angle of attack, used for the design of the blade. Most often the angle is chosen to be close to the angle, that gives maximum glide ration, see figure that means in the range from 5 to 10°, but near the tip of the blade the angle is sometimes reduced.

Chord length C_r

The standard formula for chord length is $C_r = \frac{1}{B} * \frac{16\pi r}{C} \sin^2\left(\frac{1}{3} * \arctan\left(\frac{R}{Xr}\right)\right)$ [2]

Forces acting on the Blade

There are mainly two types of forces acting on windmill blade termed as Lift forces and Drag forces.

Lift force (F_l) is nothing but the force exerted by wind on the object. The lift is always right angles to the wind direction at the object. The Drag Force (F_d) is parallel to the direction of motion. We want to make this force small [2].

Mathematical equations for these forces can be written as :

$$Fl = 0.5 * Cl * \varrho * w^2 * (bc) * B$$

$$Fd = 0.5 * Cd * \varrho * w^2 * (bc) * B$$

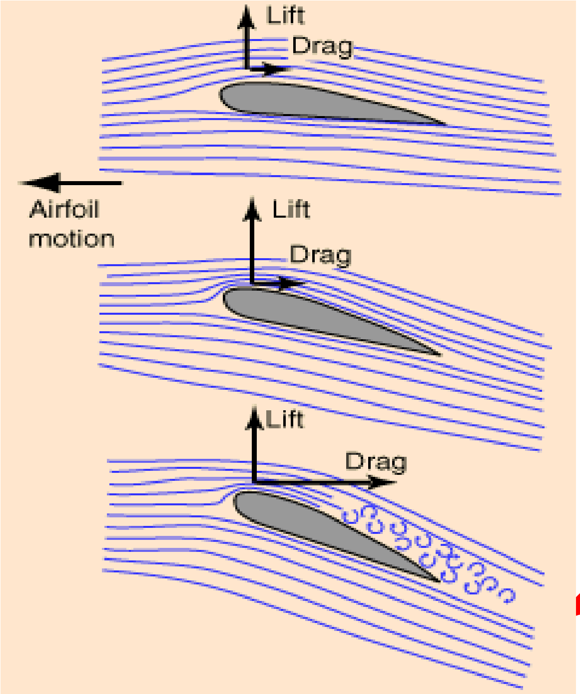


Fig 2.6 Lift and drag forces on the blade [10]

2.3 Main shaft:

The main shaft transmits the rotational energy from the rotor hub to the gearbox or directly to the generator. Moreover, the purpose of the main shaft is to transfer loads to the fixed system of the nacelle. In addition to the aerodynamic loads from the rotor, the main shaft is exposed to gravitational loads and reactions from bearings and gear.

The main shaft is also subjected to tensional vibrations in the drive train. Such vibrations will usually be of importance to possible frictional couplings like shrink fit couplings between shaft and gear. A wind turbine can be exposed to large transient loads. Therefore, it has to be considered whether the chosen structural material possesses the necessary ductility.

This is particularly important if the turbine is to be operated at low temperatures. Since corrosion may imply a considerable reduction of the assumed fatigue capacity, it should be ensured that the shaft is protected against corrosion. Suitable quality assurance should be implemented to make sure that the geometrical and mechanical assumptions for the design are fulfilled, e.g. surface roughness, that the specified values of material parameters are met, and that the imperfections of the material do not exceed any critical level.

Fatigue loads consist of histories of stress amplitudes. One history per load component exists. Hence, a combination of fatigue loads implies a combination of stress histories. Unless the phase differences between the individual load components are known, the largest stress amplitude of one load component is to be added to the largest stress amplitude of each of the other load components, the second largest amplitude is to be added to the second largest amplitude of each of the other load components, and so forth[9] Material used for this shaft is non- or low-alloyed machinery steels, i.e. steel with a carbon content of 0.3-0.7% and with less than 5% alloy of metals such as Mn, Cr, Mo, Ni and V. [9]

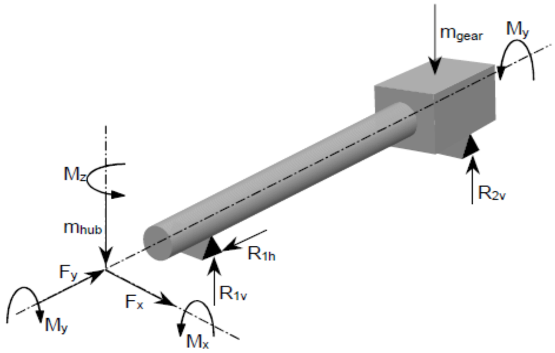


Fig 2.7 Loads and reactions on the main shaft [9].

2.4 Main Bearing:

The main bearing of a wind turbine supports the main shaft and transmits the reactions from the rotor loads to the machine frame. On account of the relatively large deformations in the main shaft and its supports, the spherical roller bearing type is often used.

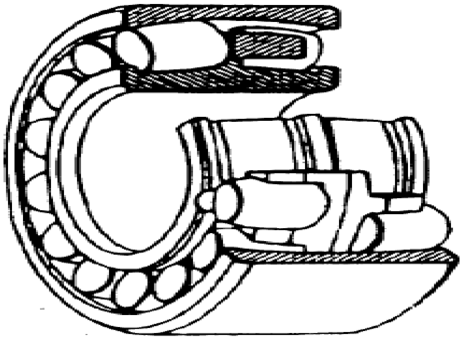


Fig 4.8 Spherical roller bearing [9].

We used ISO 281 Roller bearings – Dynamic load ratings and rating life + Amendment 1 and 2.

2.5 Alternator:

For this windmill we used Permanent Magnet Alternator whose rated Power is 200 watt when wind speed is 4.9 M/s from which we can generate 1kw power.

2.6 Installation:

Whole assembly is assembled and mounted on the 6 meter heighted, 'C' class, MS pole of 120mm diameter and fixed in simple RCC with the help of 'J' hooks. To avoid the deflection of pole we have used 3 guy wires as a support to the structure. The actual photograph of this is shown below.

The installation unit is consist of number of elements which are shown in the following circuit.

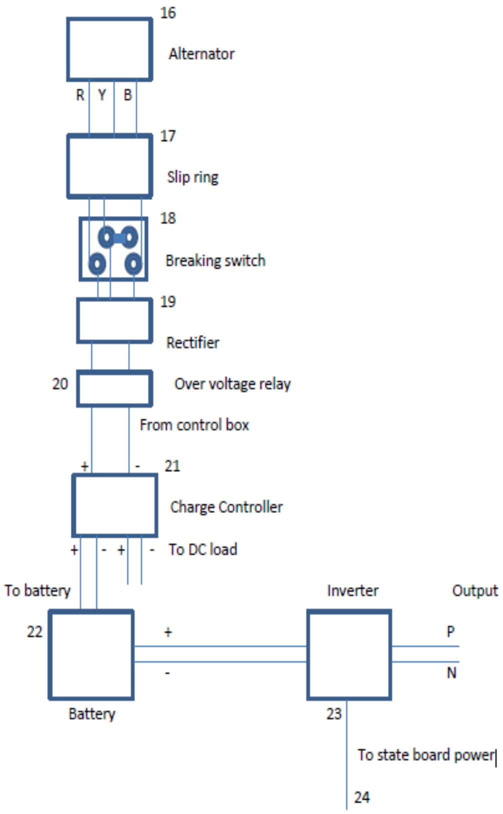


Fig: Installation unit of windmill

3. RESULTS

1] Testing of composite material required for manufacturing the blade.

Sr no	Details	Observations
1	10*10*3 mm plate	Breaking load = 133.27 Kgf/mm2

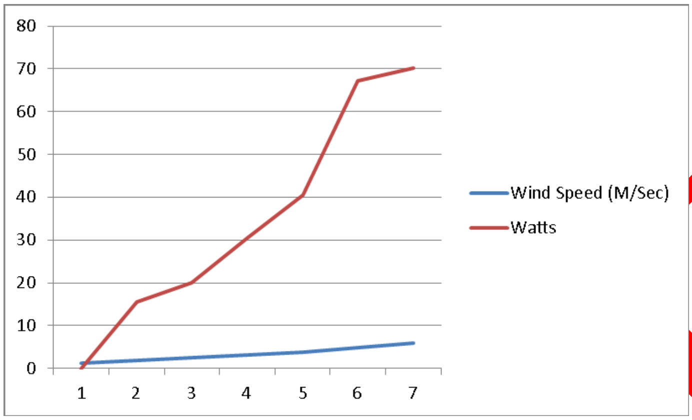
2]Power Generation as per Wind speed and RPM speed of Turbine is shown in the given table:

Wind Speed (m/sec)	Power (Watts)	Turbine RPM
1.2	1.15	50
1.8	26.14	100
2.5	50	150
3.2	75.83	200

3.9	83.5	250
4.9	93	300
6.0	115	400

Table: Readings taken on HAWT

According to the above readings the graph between windspeed and power generation can be drawn as shown below:



Graph : Wind speed Vs. Power Generated

While taking actual readings we found that the rated wind speed of this windmill is 4.9 meter per second and it can generate 5KWh per day i.e. 5 units of elecrticity.

4. CONCLUSION

From this research we conclude that;

1. We can use the Polymer composite and glass fibres for the manufacturing of the windmill blades.
2. As wind speed increses there is increase in the output power i.e. output wattage.
3. We can achieve more than 50% cost reduction in manufacturing of blades of the wind Turbine.

The comparison between convensional windmill to our winmill is tabulated below:

Parameter	**PP_GF Blades HAWT**	**Carbon fiber Blades HAWT**
Cost	65000 rupees	200000 rupees per

	per kw	kw
Efficiency	57.56 %	64.56%
Weight of Blade	2.3 kg	1.7 kg
Strength	Moderate	High
Operating condition	All weather	All weather

5. ACKNOWLEDGEMENT

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