International Journal of Research in Engineering, Science and Management
Volume-1, Issue-9, September-2018
www.ijresm.com | ISSN (Online): 2581-5782

Design and CAD development of Low Cost Vertical Axis Wind Turbine

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***Abstract*—The need of the domestic power has been rising over the period of time. This leads to the innovative developments of the non-conventional power generating source to meet the demand. Hence the usage of the natural resources came into the usage such as wind energy and solar energy. In the current project the design of the vertical axis wind turbine of the domestic usage. The blades of the turbine are designed in such a way to increase the maximum lift of the blade for the small area of wind impact. The project also concerned about the design of the auxiliary equipment for the storage and usage of the potential generated by the turbine. The equipment dimensions will be of convenient size and can be installed over the roof tops of the residencies.**

***Index Terms*—Blade design, Non-conventional energy sources. Power harvesting, vertical axis wind turbine.**

I. Introduction

Since the seventh Century, individuals have been utilizing the wind to make their life less demanding. The primary thought of the windmills was initially put to use by Persians. Since the production of windmills, there has been numerous attempts to enhance the idea, because of tests, number of blades in the windmill has diminished. Present day windmills have 5-6 blades while in the past it had 4-8 blades. Additionally, past windmills must be physically pointed into the wind bearing, while the advanced model can be transformed into the wind naturally. What's more, the sail design and its materials of development have been changed throughout the years. Wind Energy As an asset which is all around existed, wind can fulfill a significant number of human's vitality necessities on the off chance that it utilized viably on a substantial scale.

Vertical axis wind turbine which is working around the vertical axis and opposite to the ground can be effective as the horizontal axis wind turbine that is working by turning in a parallel axis to the ground. In this way, it has numerous favorable circumstances over the ultimately said. It tends to be a down to earth, more straightforward and a less expensive decision to build and keep up than the horizontal axis wind turbine. They additionally have other included favorable circumstances, for example, they are continually confronting the wind movement which can accomplish our principle point in building a less expensive, cleaner and inexhaustible wellspring of power that can perform in a less demanding way. The principle idea of VAWT that it works by changing over the wind capacity to a power frame. Specifically, this model of turbines has a rotor shaft that is masterminded vertically. By this game plan, numerous favorable circumstances can be finished up. Initially, the generators and gearboxes can be settled or set near the ground. Besides, the VAWT don't should be pointed into wind bearing of movement.

In nowadays, there are numerous sorts of VAWT: Savonius, Darrieus and Giromill turbine which is less expensive and less complex to work than the standard Darrieus turbine, anyway it needs solid winds to begin. Additionally, they can function admirably in 2 irritated wind conditions. The fundamental element of this game plan is that the turbine does not should be put into the wind to be productive. The Giromill sharp edge design is easy to build, however it prompts a bigger structure than the customary course of action, and needs more grounded blades [2].

II. wind Turbine Types

Wind turbines can be ordered in a first estimate as indicated by its rotor axis introduction and the sort of aerodynamic forces used to take energy from wind. There are a few different highlights like power rating, measurements, number of blades, power control, and so on that are talked about further along the design procedure and can likewise be utilized to characterize the turbines in more particular classifications.

A. Rotor Axis Introduction

The significant characterization of wind turbines is identified with the pivoting axis position in regard to the wind; care ought to be taken to keep away from disarray with the plane of turn

B. Horizontal Axis Wind Turbines (HAWT)

The rotational axis of this turbine must be situated parallel to the wind with a specific end goal to create power. Various sources guarantee a noteworthy productivity for each same swept area and the lion's share of wind turbines are of this compose.

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C. *Vertical Axis Wind Turbines (VAWT)*

The rotational axis is opposite to the wind heading or the mounting surface. The primary advantage is that the generator is on ground level so they are more open and they needn't bother with a yaw framework. In light of its nearness to ground, wind speeds accessible are lower. One intriguing advantage of VAWTs is that blades can have a steady shape along their length and, not at all like HAWTs, there is no need in turning the cutting edge as each section of the sharp edge is subjected to a similar wind speed. This permits a less demanding design, fabrication and replication of the edge which can impact in a cost decrease and is one of the principle motivations to design the wind turbine with this rotor arrangement.

III. Force or Drag Compose

There are two different ways of removing the energy from the wind contingent upon the fundamental aerodynamic forces utilized:

- The drag compose takes less energy from the wind yet has a higher torque and is utilized for mechanical applications as pumping water. The most delegate model of drag-type VAWTs is the Savonius.
- The lift compose utilizes an aerodynamic aerofoil to make a lift force, they can move snappier than the wind stream. This sort of windmills is utilized for the age of power. The most delegate model of a lift-type VAWT is the Darrieus turbine; its blades have a troposkien shape which is fitting for standing high centrifugal forces.
- The design thought is to influence a lift to type turbine, with straight blades rather than bended. This sort of gadget is additionally called giromill and its power coefficient can be higher than the most extreme conceivable proficiency of a drag compose turbine, as Savonius (Claessens, 2006).

IV. Giromill Rotors

- *Blades:* Giromill rotor has a vertical aerofoils blades like the Darrieus compose. Be that as it may, the Giromill rotor blades are straight. The blades real capacity is to turn by the wind activity. These blades are introduced and settled to the rotor shaft that is associated with them and pivots in the meantime. Blades numbers is a vital issue. By and large, it is considered as a few blades, anyway these are not by any means the only decision. These turbines may confront a proficiency misfortune, yet expanding the quantity of blades results that the turbine is managing more drag. The wind turbines that have countless, has a generally low speed of pivot. The torque vibration can be diminished by utilizing at least 3 blades, which prompts a more noteworthy strength for the Darrieus rotor wind turbine, while the negative purpose of expanding blades number is taken a toll. Figure 2.2 shows distinctive kinds of NACA aerofoils. Each compose has diverse properties, for example, organizes and harmony length.
- *Axis of Pivot:* It is characterized as the central mast. It lies in the focal point of the rotor encompassed by alternate parts. When all is said in done, it is metallic and has a round section.
- *Darrieus Rotor Mechanism of Action:* Darrieus rotor strategy for work can be rearranged as underneath. Initially, the bothered wind that faces the rotor keeps straight. At the same, the blades tips are turning speedier than the fundamental undisturbed wind speed. For instance the tip proportion of sharp edge speed because of free wind speed is bigger than 3. At the point when the TSR is high, the aerofoils will cut along the wind with a little approach. Therefore, the lift force continually helps the rotor turning when the drag force stands up to. As a rundown, work technique for Giromill VAWT is the same as the far reaching Darrieus turbine. The blades are turn by wind and its speed is partitioned into lift and drag forces. Therefore, the resultant of the two speed segments makes the turbine pivot. The general area of the Giromill VAWT is spoken to by the length of blades duplicated by the rotor distance across. Fig beneath speak to the guideline of the Darrieus Rotor.

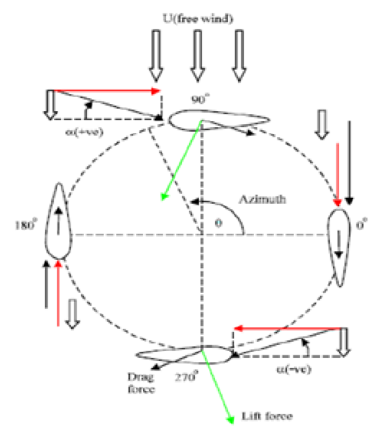

Fig. 1. Principles of Darrieus rotor

- The primary issue looked with this design is that the AOA changes while the turbine turns, so every one of the blades delivers the greatest torque at two focuses on the cycle. Second negative point is that the greater part of the mass of the turning movement is situated at the limit rather than the inside like the fan structure. This issue, causes a high centrifugal weights on the procedure of work that must be heavier and more grounded so it can oppose these burdens. Generally the shape resembles an egg-mixer machine, which used to keep away from this issue, on the grounds that the mass is pivoting far from the revolution axis. Above Fig demonstrates the bearing of rotor pivoting [5].It can be noticed that the resultant force because of wind speed decides the approach at which the cutting edge has the most extreme wind impact on its area. In this manner, having a more noteworthy resultant force will build the lift force and the speed of rotor which causes the turbine structure to pivot quicker. Therefore introducing a wind turbine in a high wind speed areas can be more proficient and useful bringing about a superior output of energy generation.

- *Placing Conditions:* The available wind power increases in a fast rate with respect to the speed, as a result, the conversion of wind energy should be sited in an appropriate area, where winds have high speed. While selecting the wind energy site these points should studied.
- *Velocity curve availability at a specific site:* Velocity curve with respect to time, demonstrates the maximum output of energy wind, so it can be considered as the initial principle of controlling factor for finding the electrical O/P, so that the yield returns to the wind conversion system machine. As a result, it is common to have an average wind speed of V such as: V≥12-16 km/hr., For example (3.5-4.5 m/sec)
- *Average annual wind speed:* Wind velocity is a critical value when dealing with wind energy. Wind power through a specific x-section area for a constant wind velocity can be expressed as:

$$P_w = KV^3 (\mathrm{K} = \mathrm{Constant}) \quad (1)$$

From the previous equations it is obvious that the cubic relation is dependent on wind velocity which affects the wind power output value. For example, doubling the velocity increases wind power with an 8 factor.

- *Height of the planned location:* Air density is affected by the height of site. As a result, wind power, machine conversion system and electric power are affected. When the location height increases, the wind velocity increases.
- *Ground quality:* Wind energy conversion systems should be secured in addition to having a stable ground surface.
- *Structure of wind at a specific site:* Near the ground, wind is turbulent and disturbed, so the direction of velocity varies rapidly. This caused by the symmetric flow that is collected and defined as the wind structure.
- *Structural Design:* In addition to operating at peak aerodynamic efficiency it is important to design a VAWT that can withstand lift forces, drag forces and wind loads. Structural analysis was performed on individual components of the VAWT since each part was subjected to various loads. The accompanying segments were independently examined: Driveshaft, Frame, Tower, Blades, and Bearing
- For this segment of the undertaking, fundamental solid mechanics and additionally bearing choice, producing constraints, maintenance, and transportation concerns were considered. The last report will cover a more complete structural analysis including limited component analysis (FEA), swagger estimating, vibration contemplations, jolt design or potentially weld composes. Note that the numerical qualities ascertained in this area of the report are liable to change as the design is refined and more nitty gritty streamlined demonstrating is led. The system, notwithstanding, won't change radically.
- The structural analysis was led at two operational states. The principal case inspects the turbine at most extreme working condition at a breeze speed of 26 m/s and a rotor speed of 35 rev/min. The second case looks at the turbine in a stopped condition at a breeze speed of 50 m/s, keeping in mind the end goal to agree to the IEC 61400-1 Class IA reference state.
- *Material Selection:* For structural design it is essential to consider all materials proper to the application. For the design of this turbine, the material ought to be savvy and fit for giving the required mechanical properties to every application.

Materials that were considered were steel, aluminum, and composites. Steel can be promptly dismissed because of weight. Aluminum would fulfill the weight prerequisite, however displays poor fatigue obstruction. Hence, the choice was made to utilize a composite material. A few kinds of composites that can be dismissed instantly are carbon filaments since they have inadmissible galvanic consumption properties and higher cost. Through research, it was discovered that glass-fiber composites are ordinarily utilized in present day wind turbines and display good mechanical properties.

The round and hollow help structure of the turbine will be made of structural steel, a financially savvy material regularly utilized in bigger structures. This steel is liable to change after reaching produces. The properties of structural steel are recorded in the table underneath:

- *Aerofoil of VAWT:* The sort of aerofoils that have been considered for our Giromill wind turbine design is a 4 digit NACA wing part. In this sort of NACA aerofoil (The NACA aerofoils are aerofoil shapes for air ship wings created by the National Advisory Committee for Aeronautics), the state of the NACA aerofoils is portrayed utilizing a progression of digits following "NACA". The parameters in the numerical code can be gone into equations to decisively create the cross-area of the aerofoil and compute its properties. The underlying number speaks to the bigger hunch of tension. The second number speaks to the separation of biggest tension caused by the aerofoil come about by edge in 10 % of the tension. Last two numbers speak to the most extreme thickness of the aerofoil as percent of the tension.

The aerofoil has an opening at best and base surface to associate with the radial arms. This can be unmistakably found in the Fig below which is created utilizing the 3D CAD programming. The place of the penetrate is resolved as 40% of harmony from the front end in view of the past investigations of the Giromill wind turbine.

- *Radial Arms:* The separation between focus shaft and the air thwart is called radial arm. Particular frameworks are should have been introduced for simple assembling and disassembling of aerofoil and shaft. The material utilized for creation of radial arms is aluminium on account of its light weight and high strength.

To attach the aerofoil with the arms, 6mm screws are utilized. There are two sorts of radial arms that are designed one for the best and another for the base which experiences the shaft.

For our design we have accepted a 50 cm length for each arm by approximating the length to the extent of the rotor and blades weight. Afterward, we have balanced the length to show signs of improvement twist impact over the blades zone and less misshapening of the arms. This twisting happens because of arms bowing if there should be an occurrence of incredible power over the structure of the rotor.

In the accompanying table measurements of best radial arm

TABLE I
MEASUREMENTS OF BEST RADIAL ARM

S. No.	Description	Dimension
1	Arm number	4
2	Arm length	350 mm
3	Centre Drill diameter	12mm
4	Side holes diameter	6mm
5	Position from the outer end to center	377
6	Arm dimensions	25.4*25.4 mm
7	Thickness	1 mm

- *Shaft:* The shaft is usually cylindrical, but may be square or cross- shaped in section. They are solid in cross -section but sometimes hollow shaft is also used. An axle, though similar in shape to the shaft, is a stationary machine element and is used for the transmission of bending moment only. It simply acts as a support for some rotating body such as hoisting drum in a car wheel or a rope. A spindle is a short shaft that impacts motion.

The design of the Vertical axis wind turbine deals with the design of basic structural components with suitable loads. The components to be designed are Radial arms, Design of shaft, Design of bearings.

- *Design of Radial Arms:* The arms have the bending load. The figure below shows the Bending load on radial arms.

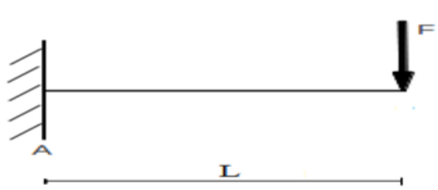

Fig. 2. Bending load on radial arms

V. CALCULATIONS

Here:

L = 0.350 (arm length is supposed)

F = 0.3kgx9.81 = 2.943 N

E = 2 X 10^{11} N/m^2

Deflection of beam at the end

$$y_{end} = \frac{wL^2}{3EI}$$

Here:

W: Aerofoil weight (N) = 0.300

E: Young's modulus in (N/m^2)

I: Moment of inertia (Kg.m^2)

Where:

E = 70 x N/m^2

Moment of inertia is represented by:

$$I = \frac{bd^3 - hk^3}{12}$$

Where,

$$I = \frac{25.4\ X\ 25.4^3 - 23.4\ X\ 23.4^3}{12}$$

= 9700.7893 mm^4

$$y_{end} = \frac{wL^2}{3EI} = = \frac{0.3*0.35*0.35}{3*2*10^{11}*9700.7893} = 0.0631\ X\ 10^{-16}\ m$$

Design of Shaft

Power is represented by Equation

$$P = \frac{2\pi NT}{60}$$

Torque is represented by

T = Wr

Where, r=0.350 m

W=sum of weights of aerofoils

Load: is represented by W = W_1+ W_2 +W_3 + W_4

The weight of aerofoils is represented by

W=4W1

The weight if aerofoil W1 are equal to = 0.3 kg

W = 1.2*9.81 = 11.72 N

The weight of radial arm is considered to be negligible

T = Wr = 11.72*0.350 = 4.1202 N-m

Taking N = 200

$$P = \frac{2\pi NT}{60} = \frac{2*3.14*200*4.1202}{60} = 86.2492\ W$$

Shaft:

Shear stress acting on shaft:

T = 4.1202 N-m

$$T = \frac{\pi}{16}\tau d^3$$

$$\tau = 25.48\ X\ 10^6\ N/m$$

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Compressive stress acts on the shaft is represented by

$$\sigma_c = \frac{P_c}{A}$$

$$P_c = (weight\ of\ 4 airfoils\ +\ weight\ of\ 4\ radial\ arms)$$

$$P_c = (1.2 + 0.881) = 20.414\ \text{kg}$$

Cross-sectional area of shaft A = $\frac{\pi}{4}d^2$ = 0.00011304 m^2

$$\sigma_c = \frac{P_c}{A} = \frac{20.414}{\frac{\pi}{4}d^2} = 180596.3121\ N/m$$

Here the design stresses of steel are:

Tensile yield strength = 2.5 X 10^8 N/m^2

Shear yield strength = $\frac{Tensile\ yield\ strength}{2}$ = 1.25 X 10^8 N/m^2

Design shear stress is represented by

$$\tau = \frac{Shear\ yeild\ strength}{factor\ of\ safety} = \frac{1.25\ X 10^8}{3} = 41\ X\ 10^6\ \text{N/m}$$

Compare with τ above

41 X 10^6 N/m >> $2.6\ X\ 10^6\ N/m$

Hence the diameter of the shaft can be taken as 12mm

TABLE II
SPECIFICATIONS OF SHAFT

S. No.	Description	Dimension
1	Diameter shaft	12mm
2	Length of shaft	150 mm

Power Calculations:

The power generated by the airfoil is the Lift force and which is highly dependent on the airfoil angle of attack. In the present analysis the angle of attack of 15° is chosen because of its higher coefficient of lift factor compared to other arrangements.

TABLE II
COEFFICIENT OF LIFTS FOR ANGLE OF ATTACKS

S. No.	Angle of Attack	Coefficient of Lift
1	0	-0.0044
2	5	0.5438
3	10	0.9067
4	15	0.4365

Lift force:

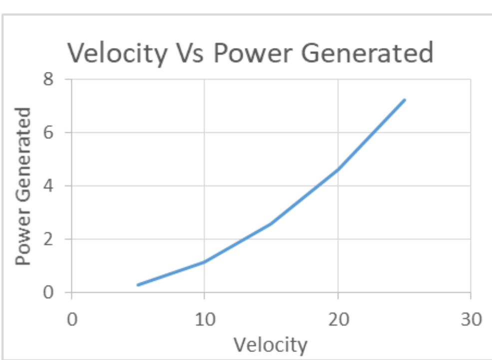

Fig. 3. Velocity vs. Torque

L = 0.5*(C_L)*ρ * V^2 * S
Where,
S = Surface area, m^2
C_L = Coefficient of lift
ρ = Density of air, kg/m^3
V = Velocity of air, m/s

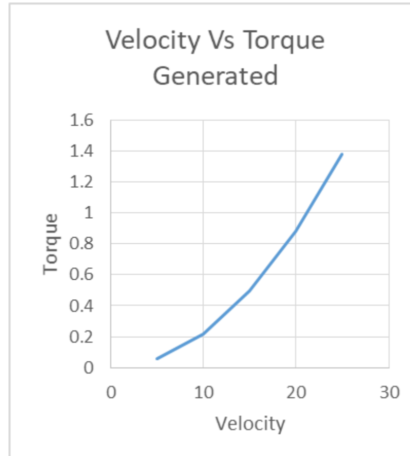

Fig. 4. Velocity vs. Power generated

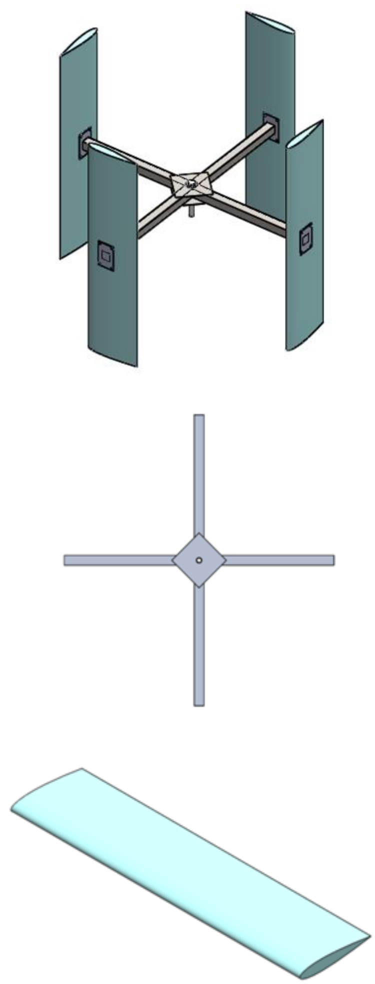

Fig. 4. CAD model

TABLE III
DIFFERENT VALUES OF POWER GENERATION FOR THE DIFFERENT VELOCITIES OF AIR FOR THE GIVEN ARRANGEMENT OF THE AIR FOILS

Angle of attack	**15º**				
Coefficient of lift	0.4365	0.4365	0.4365	0.4365	0.4365
Surface area (m^2)	0.2139085	0.213909	0.213909	0.213909	0.213909
Density kg/m^3	1.225	1.225	1.225	1.225	1.225
Velocity (kmph)	5	10	15	20	25
Velocity(m/s)	1.38885	2.7777	4.16655	5.5554	6.94425
Lift (N)	0.110313603	0.441254	0.992822	1.765018	2.75784
Arm Length (m)	0.5	0.5	0.5	0.5	0.5
Torque N-m	0.055156802	0.220627	0.496411	0.882509	1.37892
RPM	50	50	50	50	50
Power generated (W)	0.288653928	1.154616	2.597885	4.618463	7.216348

The above table shows the different values of power generation for the different velocities of air for the given arrangement of the air foils.

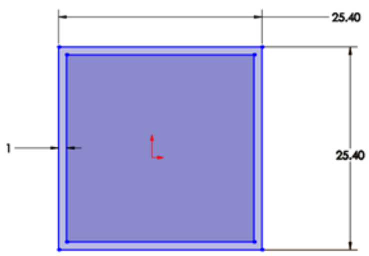

Fig. 5. Cross-section of radial arm

VI. CONCLUSION

We have designed and developed a CAD Model of a vertical axis Wind turbine and its components with 4 blades and we have obtained power generated at different velocities at 15o of angle of attack.

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