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Design and Fabrication of Vertical Axis Economical wind mill

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Abstract-From the recent surge in fossil fuels price, demands for cleaner energy sources and government funding incentives, wind turbine are becoming more viable technology for electrical power generation. Fortunately there is an abundance of wind energy to be harnessed. Today, wind turbines have to compute with many other energy sources. It is therefore important to be cost effective and for that there need to meet any load requirements and produce energy at a minimum cost per dollar of investment. Performance characteristics such as power output versus wind speed or versus angular velocity must be optimized in order to compete with other energy sources. Vertical Axis Wind Mill (VAWM) is a type of wind turbine where the main rotor shaft is set vertically. Among the advantages of this arrangement are that generators and gearboxes can be placed close to the ground, and that VAWTs do not need to be pointed into the wind. AVAWTtipped sideways, with the axis perpendicular to the wind streamlines, functions similarly. A more general term that includes this option is 'transverse axis wind turbine'. The main advantage is that, it is economically eco-friendly.

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I INTRODUCTION

Wind energy is one of the most important types of renewable energy using which is inevitable in today's world. Using this energy has been taken into consideration from the past and first it was used as windmills for daily use and now, in developed countries, it is utilized in different kinds of wind turbines with multi-megawatt power of energy generation. In our country, extreme reliance to non-renewable resources and production of pollutions in metropolises has encouraged the researchers and officials to find a renewable replacement, which is dependent on the construction and designing of wind turbines through the available technologies.

Currently two kinds of wind turbines, among different designs considered by the designers, are horizontal axis wind turbine (HAWT) and vertical axis wind turbine (VAWT), used mainly to generate power. In comparison, each one has its own advantages and disadvantages. Some advantages of vertical axis turbine are easy designing and construction, lower cost, no need to rotor yaw mechanism (Yaw) to find that wind direction and sound pollution and ecosystem damage reduction. Among its disadvantage are less efficiency, power production with higher fluctuation, lower speed of the blades and lower energy yield.

However, there are also downfalls to the VAWM. Firstly, boundary layer affects from the ground influence the air stream incident on the VAWT, which in some cases leads to inconsistent wind patterns. Secondly, VAWT are not self - starting currently, an outside power source is required to start turbine rotation until a certain rotational speed is reached.

The global need for energy increases as our civilization ages. Homes that once were powerless are now connecting to an electricity grid. New homes are being built as the world population grows. These new homes also require power from an aging electricity grid, a supplemental system is required. This system will offset cost reduction to power my home and in turn reduce the load on the existing electricity grid. If this idea were to be adopted by others, then the negative impact of additional energy plants on the environment can be reduced.

This project determines the optimal size for a wind turbine to supplement power requirement to light at least a bulb in single household. The system design requirements for the desired wind turbine system are identified in this project. This project documents the processes required for designing and implementing a wind turbine system.

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A. Classification Of Wind Turbine According To Axis

- Vertical Axis Wind turbine
- Horizontal Axis Wind Turbine

Horizontal-Axis Wind Turbines (HAWTs) contains blades which are attached to a central perpendicular to axis shaft. The shaft is attached to an alternator located at the bottom of the shaft, sometimes even at ground level. When the blades rotate, they spin the rotor of the generator, producing electricity. In this type the main rotor shaft is set vertically and the main components are located at the base of the turbine. Though it provide enough power source but still it is less advantages than vertical axis wind mill/turbine.

Vertical-Axis Wind Turbines (VAWTs) are a type of wind turbine where the main rotor shaft is set traverse, not necessarily vertical, to the wind and the main components are located at the base of the turbine. This arrangement allows the generator and gearbox to be located close to the ground, facilitating service and repair. VAWTs do not need to be pointed into the wind,which removes the need for wind-sensing and orientation mechanisms. Major drawbacks for the early designs (Savonius, Darrieus and giromill) included the significant torque variation during each revolution, and the huge bending moments on the blades. Later designs solved the torque issue by providing helical twist in the blades.A VAWT tipped sideways, with the axis perpendicular to the wind streamlines, functions similarly. A more general term that includes this option is "transverse axis wind turbine".

B. *Various Types Of Vertical Axis Wind Turbine*

- Darrieus Wind Turbine
- Savonius Wind Turbine

The original Darrieus patent, US Patent 1835018, includes both options.Drag-type VAWTs such as the Savonius rotor typically operate at lower tipspeed ratios than lift-based VAWTs such as Darrieus rotors and cyclo-turbines. The forces and the velocities acting in a Darrieusturbine are depicted in figure. The resultant velocity vector $\vec{W}$, is the vectorialsum of the undisturbed upstream airvelocity $\vec{U}$, and the velocity vector of the advancing blade $-\vec{\omega} \times \vec{R}$□

$$\vec{W} = \vec{U} + \left(-\vec{\omega} \times \vec{R}\right)$$

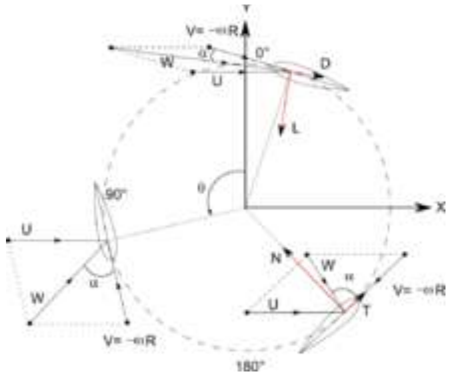


Fig: Forces and velocities acting in a Darrieus turbine for various azimuthal positions

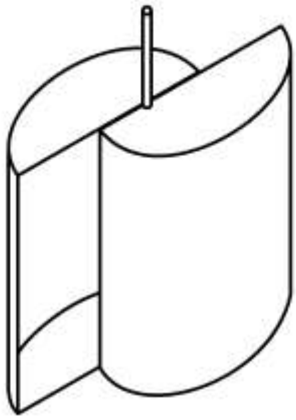
Thus the oncoming fluid velocity varies during each cycle. Maximum velocity is found for θ=0 degreeand the minimum is found for θ=180 degree, where (θ) is the azimuthal or orbital blade position. The angle of attack (∝)is the angle between the oncoming air speed and the blade's chord. The resultant airflow creates a varying, positive angle of attack to the blade in the upstream zone of the machine, switching sign in the downstream zone of the machine.From geometrical considerations, the resultant airspeed flow and the angle of attack are calculated as follows:

$$W = U\sqrt{1 + 2\lambda\cos\theta + \lambda^2}$$

$$(\propto) = \tan^{-1}\left(\frac{\sin\theta}{\lambda + \cos\theta}\right)$$

$$(\lambda) = \frac{wR}{U}$$

The Savonius wind turbine was invented by the Finnish engineer Sigurd Johannes Savonius in 1922. However, Europeans had been experimenting with curved blades on vertical wind turbines for many decades before this. The earliest mention is by the Italian Bishop of Czanad, who was also an engineer. He wrote in his 1616 book *Machinae novae* about several vertical axis wind turbines with curved or V-shaped blades. None of his or any other earlier examples reached the state of development made by Savonius. In his Finnish biography there is mention of his intention to develop a turbine-type similar to the Flettner-type, but autorotationary. He experimented with his rotor on small rowing vessels on lakes in his country. There are no results of his particular investigation known, but Magnus-Effect is confirmed by König. The two Savonius patents: US1697574 filed 1925 by Sigurd Johannes Savonius. AndUS1766765filed 1928.

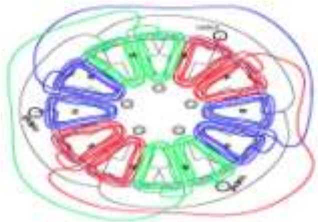


Schematic drawing of a two-scoop Savonius turbine

II COMPONENTS

A. *Guide Wire*

Vertical axis wind turbine normally needs guide wire to keep the rotor shaft in a fixed position and maximized possible mechanical vibration.



B. *Hub*

The hub is the centre of the rotor to which the rotor blades are attached. Cast iron or cast steel is most often used. In VAWT there are two hibs upper and lower because blades are attached at two points.

C. *Rotor*

The rotor is the heart of a wind turbine and consists of multiple rotor blades attached to a hub. It is the turbine component responsible for collecting the energy present in the wind and transforming this energy into mechanical motion. As the overall diameter of the rotor design increases, the amount of energy that the rotor can extract from the wind increases as well. Therefore, turbines are often designed around a certain diameter rotor and the predicted energy that can be drawn from the wind.

D. Blades

Rotor blades are a crucial and basic part of a wind turbine. They are mainly made of aluminium, fiber glass or carbon fiber because they provide batter strength to weight ratio. The design of the individual blades also affects the overall design of the rotor. Rotor blades take the energy out of the wind; they "capture" the wind and convert its kinetic energy into the rotation of the hub. There are two types of blades use in VAWT

- Drag force type blades (savonius wind turbine)
- Lift force type blades (Darrieus and giromill wind turbine)

E. Shaft

The shaft is the part that gets turned by the turbine blades. It in turn is connected to the generator within the main housing.

F. Brake

Braking of a small wind turbine can also be done by dumping energy from the generator into a resistor bank, converting the kinetic energy of the turbine rotation into heat. This method is useful if the kinetic load on the generator is suddenly reduced or is too small to keep the turbine speed within its allowed limit. Cyclically braking causes blades to slow down, increases the stalling effect and reduces efficiency of the blades. This way, the turbine's rotation can be kept at a safe speed in faster winds while maintaining (nominal) power output. This method is usually not applied on large grid-connected wind turbines.

A mechanical brake is normally placed on the high speed shaft between the gearbox and the generator, but there is some turbine in which the brake is mounted on the low speed shaft between the turbine and gear box.

A mechanical drum brake or disk brake is use to stop turbine in emergency situation such as extreme gust events or over speed. This brake is also used to hold the turbine at rest for maintenance as a secondary mean, primarily mean being the rotor lock system. Such brakes are usually applied only after blade furling and electromagnetic braking have reduced the turbine speed generally 1 or 2 rotor RPM, as the mechanical brakes can create a fire inside the nacelle if used to stop the turbine from full speed. Also the load on turbine increases if brake is applied on rated RPM. Such kind of mechanical brake are driven by hydraulic systems and connected to main control box.

G. Gear

The main function of the gear box is to take low rotational speed from shaft and increase it to increase the rotational speed of the generator.Among the types of gear stages are the helical, parallel shaft, spur and worm types. Two or more gear types may be combined in multiple stages. They are made up of aluminium alloys, stainless steel and cast iron.

H. Generator

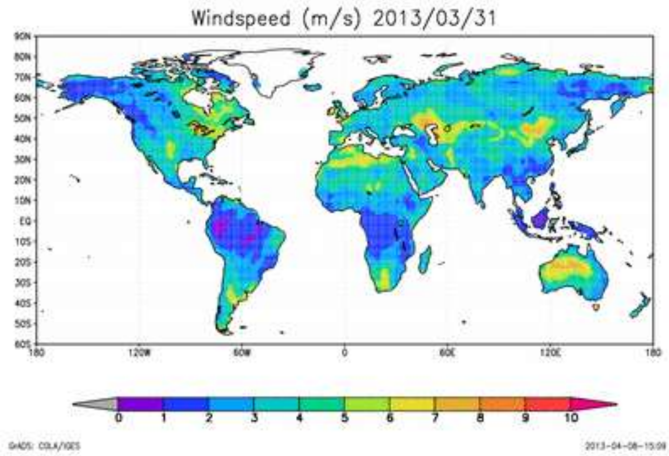
The conversion of rotational mechanical energy to electrical energy is performed by generator. Different types of generator have been used in wind energy system over the years. For large, commercial size horizontal-axis wind turbines, the generator is mounted in a nacelle at the top of a tower, behind the hub of the turbine rotor. Typically wind turbines generate electricity through asynchronous machines that are directly connected with the electricity grid. Usually the rotational speed of the wind turbine is slower than the equivalent rotation speed of the electrical network - typical rotation speeds for wind generators are 5-20 rpm while a directly connected machine will have an electrical speed between 750-3600 rpm. Therefore, a gearbox is inserted between the rotor hub and the generator by reducing cost and weight.

I. Base

Base of VAWT is usually the roof of building on which it is installed.

III THEORY OR METHODOLOGY OF DESIGN

The design of a wind turbine requires one thing most of all, wind. There is no point in designing a wind turbine system for an area where no wind is present. Aside from a very expensive form of yard artwork, it will be useless. Our first step for determining the feasibility of installing a windmill and check the availability of wind according to area of the world.



The wind at a particular location can be influenced by a number of factors such as obstruction by buildings or trees, the nature of the terrain and deflection by nearby mountains or hills. The prevailing wind direction is between south and west. Average annual wind speeds range from 3m/s in parts of south to over 8 m/s in the extreme north. On average there are less than 2 days with gales each year at inland places, but more than 50 a year at northern coastal locations. It also depends upon wind speed thresholds value in desert area.

Wind speed thresholds for different desert environments	
Environment	**Threshold wind speed**
Fine to medium sand in areas with sand dunes	16 to 24.1 kmph
Sandy areas with poorly developed desert pavement	32.2 kmph
Fine material in desert flats	32.3 to 40.2 kmph
Dry lake beds and/or crusted salt flats	48.3 to 56.3 kmph
Well-developed desert pavement	64.4 kmph

During the course of a typical day, the range (difference between the highest and lowest) of mean hourly wind speed is considerable. The mean diurnal range is 11.5 m/s in January and is still as high as 8.4 m/s in July. The diurnal variation is much more pronounced in summer than in winter. This is a result of surface heating, which increases mixing of the faster-moving air at higher levels with the air near the surface. As the effect of surface heating diminishes, the wind speed decreases and during the night there is little variation from hour to hour. The diurnal variation is greatest on sunny days and least on dull days. The tendency for maximum wind speed to occur in the afternoon is noticeable only in the long-term figures and on individual days the maximum may be at any hour. Table shown below tells the variation of wind speed on various seasons according to month from the starting of January to December.

Month	v_m (m/s)	σ	c (m/s)	k	P (W/m²)
Jan	7.44	2.38	8.27	3.45	328.71
Feb	7.36	2.45	8.21	3.51	325.41
Mar	7.76	2.43	8.34	4.26	314.11
Apr	7.35	2.14	8.13	3.81	304.18
May	6.00	1.58	6.58	4.26	158.96
June	3.58	1.24	3.91	3.09	36.08
July	3.76	1.27	4.19	3.25	43.54
Aug	3.57	0.91	3.92	4.47	35.08
Sep	5.34	1.40	5.88	4.07	113.63
Oct	7.74	1.46	8.33	6.12	312.69
Nov	7.94	1.74	8.63	5.20	348.79
Dec	7.83	1.92	8.63	4.629	252.43

Wind blows most frequently from the south and west for open sites while winds from the northeast or north occur least often. In January the southerly and south-easterly winds are more prominent than in July, which has a high frequency of westerly winds. Easterly winds occur most often between February and May and are commonly accompanied by dry weather. The influence of topography can be seen in the low frequency of winds from a south easterly direction.

IV DESIGN OF VAWT

- *DESIGN OF BLADE*

A. Assumption of VAWT

1)The wind speed is kept constant throughout the analysis at the average wind speed value according to area of region.

2) Density of air (ρ)
3) Viscosity of air (υ)
4) Number of airfoils
5) Power required (P)

B. Calculation of Area

$P=0.5\rho AV^3C_P$

C. Dimension of Blade

1) Width of blade = w

2) Height of blade = h

w=0.625h

D. Calculation Of Actual Area Of Blade

1) Number of blades = n

$w_1=0.133w$

$w_2=0.609-0.133w$

$A_{actual}=A_1+A_2$

$A_{effective}=n\,(A_{actual})$

E. Failure Analysis Of Blade

Select the material for blade from design data

Ultimate tensile strength=S_{ys}

Factor of safety=f. o .s

$\sigma_{al}=\frac{S_{ys}}{f.o.s}$

Force acting on blade (F) $=\frac{1}{2\pi}\int_0^{2\pi} F_t\,\theta\,d\theta\,A$

$F_t=0.5\rho V^2C_t$

Angle of attack $(\propto)=\tan^{-1}\frac{\sin\theta}{\lambda+\cos\theta}$

Azimuth angle= θ

Drag coefficient=C_d

Lift coefficient=C_1

$$C_t=C_d\cos\propto-C_1\sin\propto$$

Stress on blade $(\sigma_{calculated})=\frac{F}{A}$

$$(\sigma_{calculated})<\sigma$$

Hence design is safe

F. Calculation of Maximum Tangential Force

$F_{t_{max}}=\sigma_{al}A_{effective}$

- *DESIGN OF BLADE*

G. Torque

Select material of shaft

Number of revolution of turbine blade=N

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

H. Diameter of Shaft

Allowable shear stress $(\tau)=\frac{S_{ys}}{f.o.s}$

Yield tensile strength=S_{yt}

Ultimate shear strength=S_{ut}

Yield strength in shear=S_{ys}

Factor of safety=f. o. s

Shear stress=0.3 S_{yt} (or)

=0.18 S_{ut}

Select minimum value from above shear stress

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

Select standard diameter of shaft from design data

I. Stress Analysis of Shaft

Length of shaft=L

Tangential force $(F_t)=0.5\rho V^2C_t$

Bending moment of shaft (M) $=F_tL$

Moment of inertia (I) $=\frac{\pi d^4}{64}$

$Y=\frac{d}{2}$

Bending stress=σ_b

We have,

$$\frac{M}{I}=\frac{\sigma_b}{Y}$$

Also,

$$M=\frac{\pi\sigma_{b_{calculated}}d^3}{32}$$

$\sigma_{b_{calculated}}<\sigma_b$

Design is safe

J. Maximum Shear Stress and Equivalent Twisting Moment

$\tau_{max}=0.5\sqrt{\sigma_b{}^2+4\tau^2}$

$\tau_{max}<\tau$

Design is safe

$T_e=\sqrt{M^2+T^2}$

K. Wind Power Installed Capacity

Sr. No	Wind power installed capacity	
	Area	***Power(MW)***
1	Tamilnadu	2036.9
2	Maharastra	456.3
3	Karnataka	410.7
4	Rajastan	284.8
5	Gujarat	253.5
6	Andra Pradesh	120.6
7	Madhya Pradesh	28.9
8	Kerala	2.00
9	West Bengal	1.1
10	Others	0.5
11	Total in INDIA	3595

Sr. No	Wind power installed capacity	
	Area	*Power(MW)*
12	Germany	17000
13	Spain	8959
14	USA	7000
15	Denmark	3115
16	Italy	904
17	Canada	3

V LITERATURE REVIEW AND RESEARCH PAPER STUDY

These references are taken from various author book of different university's as given below.

[1] Jha, Ph.D., A.R. (2010). Wind turbine technology. Boca Raton, FL: CRC Press.

[2] Amina El Kasmi, Christian Masson, An extended k-epsilon model for turbulent flow through horizontal-axis wind turbines, Journal of Wind Engineering and Industrial Aerodynamics, Volume 96, Issue 1, January 2008, Pages 103-122, retrieved 2010-04-26.

[3] Sandra Eriksson, Hans Bernhoff, Mats Leijon, (June 2008), "Evaluation of different turbine concepts for wind power", Renewable and Sustainable Energy Reviews12 (5): 1419–1434, doi:10.1016/j.rser.2006.05.01, ISSN 1364-0321, retrieved 2010-04-26.

[4] U.S.Department of Energy. "Wind and Hydropower Technologies Program".Retrieved from http://eereweb.ee.doe.gov/windandhydro/wind_how.html in November, 2005.

[5] EERE plays a key role in advancing America's energy strategy, leading a large network of researchers and other partners to deliver innovative technologies that will make renewable electricity generation cost-competitive with traditional sources of energy.

[6] Steven Peace, AnotherApproachtoWind, retrieved 2010-04-26The U.S. Department of Energy (DOE) leads national efforts to improve the performance, lower the costs, and accelerate the deployment of wind energy technologies. DOE is linked to more patents in wind energy than any other organization,

[7] Kathy Svitil, Wind-turbine placement produces tenfold power increase, researchers say, retrieved 2012-07-31.

[8] Professor L. Chang..(2005) "Advanced Topics in Environmental Engineering -Wind Power," Ch 4. University of New Brunswick. Retrieved from http://www.ece.unb.ca/powereng/courses/EE6693/index.html in October, 2005.

[9] Lecture Time: Thursday 27/11/2007 @ 1:30 pm - 4.30 pm (Winter2007)

[10] Chiras, D. (2010). Wind power basics: a green energy guide. Gabriola Island, BC, Canada: New Society Pub.

[11] Environmental design engineering includes the creation and development of: innovative tools, approaches, methodologies and standards to improve the environmental aspects of product and process designs, including life cycle optimized products, recycling and reuse.

[12] Creative approaches for using energy, water and natural resources more efficiently, for reducing waste and for preventing pollution.Pollution and pollution control: sources, impacts and controls for water pollution, air pollution, soil pollution, solid waste and chemicals, noise and electromagnetic pollution.

[13] Sutherland, Herbert J; Berg, Dale E; Ashwill, Thomas D. (2012). "A Retrospective of VAWT Technology". Sandia National Laboratories. Retrieved 19 September 2014.

[14] Kirke, Brian Kinloch, 1998. "Evaluation of Self-Starting Vertical Axis Wind Turbines for Stand-Alone Applications". Griffith University, Australia. Retrieved from http://www4.gu.edu.au:8080/adtroot/public/adQGU

[15] Arborwind (website), "History"

[16] Reuss R.L., Hoffmann, M.J., Gregorek, G.M., December 1995. 'Effects of Surface Roughness and Vortex Generators on the NACA 4415 Air-foil, The Ohio State University, Columbus, Ohio, USA. Retrieved from http://wind.nrel.gov/OSU_data/reports/7x10/N4415_7x10.pdf

[17] Recognizing the need for a wind turbine air-foil performance data base the National Renewable Energy Laboratory (NREL), funded by the US Department of Energy, awarded a contract to Ohio State University(OSU) to conduct a wind tunnel test program.

[18] Under this program OSU has tested a series of popular wind turbine air-foils. A standard test matrix has been developed to assure that each air-foil was tested under the same conditions.

[19] Wind turbines in the field can be subjected to many and varying wind conditions, including high winds with the rotor locked or with yaw excursions. In some cases, the rotor blades may be subjected to unusually large angles of attack that possibly result in unexpected loads and deflections.

[20] In addition to documenting and analysing the current status of wind technologies and the wind industry, the objectives of the initiative are to:

a) Provide leadership in development of a cohesive long-term vision for the benefit of the broad U.S. wind power community.

b) Analysis a range of aggressive but attainable industry growth scenarios.

c) Provide best available information to address stakeholder concerns.

d) Provide objective and relevant information for use by policy and decision makers.

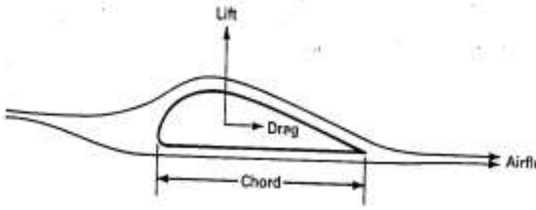
[21] Technology Review, "Will Vertical Turbines Make More of the Wind?"

[22] Dr.Gary L. Johnson, (November 21, 2001) "Wind Turbine Power – Ch 4. Wind Turbine Power, Energy and Torque."

[23] AERODYNAMICS

a) Air flow over a stationary air-foil produces two forces, a lift force perpendicular to the air flow and a drag force in the direction of air flow

b) The existence of the lift force depends upon laminar flow over the air-foil, which means that the air flows smoothly over both sides of the air-foil.



VI CONCLUSION

Our work and the result obtained so far are very encouraging and reinforce the conviction that vertical axis wind energy conversion systems are practical and potentially very contributively to the production of clean renewable electricity from the wind even under less than ideal sitting conditions. It is hoped that they may be constructed used high-strength, low-weight materials for deployment in more developed nation and settings or with very low tech local materials and local skills in less developed countries. The wind turbine designed is ideal to be located on top of a bridge or bridges to generate electricity, powered by wind. The elevated altitude gives it an advantage for more wind opportunity. With the idea on top of the bridges, it will power up street lights and or commercial use. In most cities, bridges are a faster route for everyday commute and in need of constant lighting makes this an efficient way to produce natural energy.

VII Future Scope

The development of effective alternators and dynamos can be used to harness wind energy from relatively small winds. The use of materials like acrylic plastic sheet can be used to develop low cost VAWT. If blades of larger are used with proper strength and design, the application area of VAWT can be increased in the fields like agriculture, street lighting, hospitals etc.