Aerodynamic Modeling And Analysis of Vertical Axis Wind Turbine

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Abstract

It is well known that we rely on the nonrenewable resources such as fossil fuels, oils, natural gas, etc which will certainly get exhausted some day. So keeping these items into thought we tend to thought of generating power exploitation non-conventional sources that is extravagantly accessible naturally and has zero threat for extinction. Among the various non-convention methods for generation of electric power, wind has found its place to be efficient. Wind Energy being renewable resource of energy has got much attention for power generation, nowadays. Having a nature of abundance in contrast to employment of resources in typical strategies satisfies the growing desires. Wind energy depends upon natural terrains which have wind potential, though these terrains don't seem to be found even in nature everyplace, but those which have, are the places that can be harnessed for high potential power generation. Taking into consideration the geographical attributes of our region, the vertical axis windmill are economical for power generation. The basic reason for using VAWT is that, it does not consider the wind direction and operates at low wind speed.

Keywords:-*VAWT, Wind Energy, Blades, Aerofoil*

1. Introduction:-

At present, there square measure 2 classes of contemporary wind turbines, specifically horizontal axis wind turbines (HAWTs) and vertical axis wind turbines (VAWTs), that square measure used primarily for electricity generation and pumping water. The main advantage of VAWT is its single moving part (the rotor) where no yaw mechanisms are required, thus simplifying the design configurations significantly. Blades of straight-bladed VAWT is also of uniform section and straight, creating them comparatively simple to fabricate or produce, in contrast to the blades of HAWT, which should be twisted and tapered for optimum performance. Furthermore, almost all of the components of VAWT requiring maintenance are located at the ground level, facilitating the maintenance work appreciably. From the past experiences, it is evident that wind turbines can compete with conventional sources in niche markets, and lower costs make them affordable options in increasingly large markets. Environmentally benign VAWTs are often utilised for a variety of applications, together with (i) electricity generation; (ii) pumping water; (iii) purifying and/or desalinating water by reverse osmosis; (iv) heating and cooling using vapour compression heat pumps; (v) commixture and aerating water bodies; and (vi) heating water by fluid turbulence. In general, VAWT can sensibly be used in any area with sufficient wind, either as a stand-alone system to supply individual households with electricity and heat, or for the operation of freestanding technical installations. If a network connection is available, the energy can be fed in, thereby contributing to a reduction in electricity costs. In order to maximise the protection of the energy offer, differing types of VAWT are often supplemented by a electrical phenomenon system or a diesel generator during a fast and uncomplicated fashion. Through the combination of several VAWTs with other renewable energy sources and a backup system, local electrical networks can be created for the energy supply of small settlements and remote locations

1.1 Background:-

Straight-bladed vertical axis wind turbine (SB-VAWT) is the simplest types of Turbo machines which are mechanically easy to construct. Design parameters for cost-effective SB-VAWT are selection of blade material. SB-

VAWT blades must be produced at moderate cost so that the energy to be competitive in price and the blade should last between 20 and 30 years. Though horizontal axis wind turbines (HAWTs) work well in rural settings with steady unidirectional winds, SB-VAWTs have various advantages over them. Unlike HAWTs, fixed-pitch SB-VAWTs are mechanically simpler and they do not require additional components (like yaw mechanics, pitch control mechanism, wind-direction sensing device). Furthermore, almost all of the components requiring maintenance are located at the ground level, facilitating the maintenance work appreciably. Wind energy is an important form renewal source of energy. Wind energy is the clean source of energy. Here our focus to study of the history of vertical axis wind turbine and basic study of the various types of airfoil used for wind turbine blade. This paper also presents the conceptual study of the terms used in basic wind turbine design. For a VAWT the blades perform the main role to extract energy from the wind. Curved blade is considered as the blade for this new design of VAWT. Airfoil has some good aerodynamic characteristics, match with the characteristics of Savonius type VAWT, such as good stall characteristics and little roughness effect, relatively high drag and low lift coefficient. India's ranking is fifths position in world based on the installed wind power producing capacity. India is producing around 2 billion kWh per year from wind with the average utilization factor of 1175 hours per year. Cost of energy from wind is about Rs.4 to 5 per kWh in India. India has also started exporting 1 MW capacity machines. Data are available about its availability pattern around the day for different months of the year.

Figure No 1:- Straight Blade VAWT

1.2 Types:-

1. **Horizontal Axis Wind Turbine (HAWT)**
2. **Vertical Axis Wind Turbine (VAWT)**
3. **Savonius wind turbines.**
4. **Darrieus Wind Turbines**

- **Horizontal Axis Wind Turbine (HAWT):-**
  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.

- **Vertical-axis wind turbines :-**

Vertical-axis wind turbines (or VAWTs) have the main rotor shaft arranged vertically. One advantage of this arrangement is that the turbine does not need to be pointed into the wind to be effective, which is an advantage on a site where the wind direction is highly variable. It is also an advantage when the turbine is integrated into a building because it is inherently less steerable. Also, the generator and gearbox can be placed near the ground, using a direct drive from the rotor assembly to the ground-based gearbox, improving accessibility for maintenance. However, these designs produce much less energy averaged over time, which is a major drawback.

- **Savonius wind turbines:-**

Savonius wind turbines are a type of vertical-axis wind turbine (VAWT), used for converting the force of the wind into torque on a rotating shaft. The turbine consists of a number of aerofoils, usually—but not always—vertically mounted on a rotating shaft or framework, either ground stationed or tethered in airborne systems. The Savonius turbine is one of the simplest turbines. Aerodynamically, it is a drag-type device, consisting of two or three scoops. Looking down on the rotor from above, a two-scoop machine would look like an "S" shape in cross section. The differential drag causes the Savonius turbine to spin. Because they are drag-type devices, Savonius turbines extract much less of the wind's power than other similarly-sized lift-type turbines. Much of the swept area of a Savonius rotor may be near the ground, if it has a small mount without an extended post, making the overall energy extraction less effective due to the lower wind speeds found at lower heights.

- **Giromill/ Darrieus VAWT:-**

A subtype of Darrieus turbine with straight, as opposed to curved, blades. The cycloturbine variety has variable pitch to reduce the torque pulsation and is self-starting. The advantages of variable pitch are: high starting torque; a wide, relatively flat torque curve; a higher coefficient of performance; more efficient operation in turbulent winds; and a lower blade speed ratio which lowers blade bending stresses. Straight, V, or curved blades may be used.

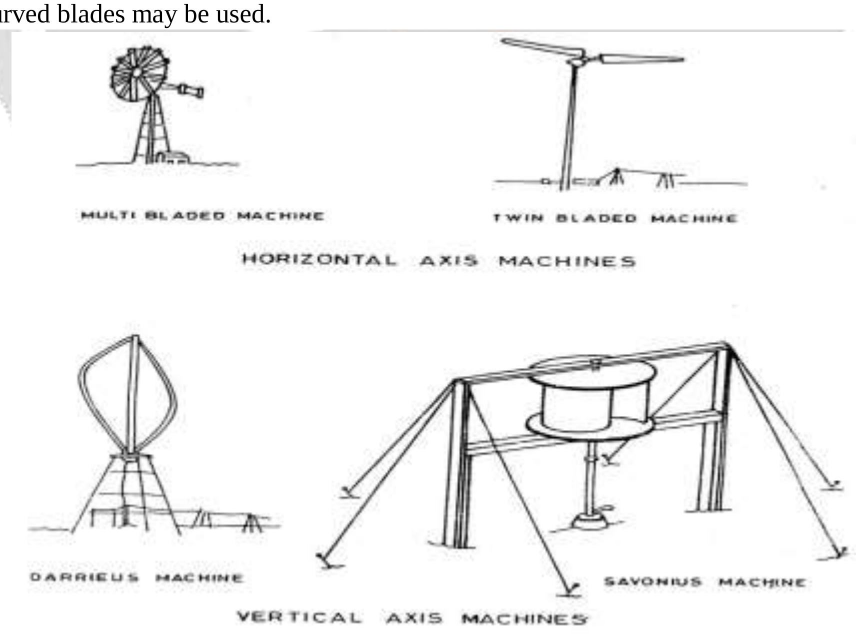


Figure No 2:- Various Types of VAWT

2. Principle /Working:-

Working of a SB-Vertical axis wind turbine is very simple as the main rotor shaft arranged vertically. One advantage of this arrangement is that the turbine does not need to be pointed into the wind to be effective, which is an advantage on a site where the wind direction is highly variable. It is also an advantage when the turbine is integrated into a building because it is inherently less steerable. Also, the generator and gearbox can be placed near the ground, using a direct drive from the rotor assembly to the ground based gearbox, improving accessibility for maintenance. In the original versions of the Darrieus design, the aerofoils are arranged so that they are symmetrical and have zero rigging angle, that is, the angle that the aerofoils are set relative to the structure on which they are mounted. This arrangement is equally effective no matter which direction the wind is blowing in contrast to the conventional type, which must be rotated to face into the wind. When the Darrieus rotor is spinning, the aerofoils are moving forward through the air in a circular path. Relative to the blade, this oncoming airflow is added vectorially to the wind, so that the resultant airflow creates a varying small positive angle of attack (AoA) to the blade. This generates a net force pointing obliquely forwards along a certain 'line-of-action'. This force can be projected inwards past the turbine axis at a certain distance, giving a positive torque to the shaft, thus helping it to rotate in the direction it is already travelling in. The aerodynamic principles which rotate the rotor are equivalent to that in autogiros, and normal helicopters in autorotation. As the aerofoil moves around the back of the apparatus, the angle of attack changes to the opposite sign, but the generated force is still obliquely in the direction of rotation, because the wings are symmetrical and the rigging angle is zero. The rotor spins at a rate unrelated to the wind speed, and usually many times faster. The energy arising from the torque and speed may be extracted and converted into useful power by using an electrical generator. The aeronautical terms lift and drag are, strictly speaking, forces across and along the approaching net relative airflow respectively, so they are not useful here. We really want to know the tangential force pulling the blade around, and the radial force acting against the bearings. When the rotor is stationary, no net rotational force arises, even if the wind speed rises quite high—the rotor must already be spinning to generate torque. Thus the design is not normally self-starting. Under rare conditions, Darrieus rotors can self-start, so some form of brake is required to hold it when stopped. One problem with the design is that the angle of attack changes as the turbine spins, so each blade generates its maximum torque at two points on its cycle (front and back of the turbine). This leads to a sinusoidal (pulsing) power cycle that complicates design. In particular, almost all Darrieus turbines have resonant modes where, at a particular rotational speed, the pulsing is at a natural frequency of the blades that can cause them to (eventually) break. For this reason, most Darrieus turbines have mechanical brakes or other speed control devices to keep the turbine from spinning at these speeds for any lengthy period of time. Another problem arises because the majority of the mass of the rotating mechanism is at the periphery rather than at the hub, as it is with a propeller. This leads to very high centrifugal stresses on the mechanism, which must be stronger and heavier than otherwise to withstand them.

2.1 Wind Turbine Units:-

A wind turbine generator consists of the following major units:

- Wind turbine with Horizontal or Vertical axis.
- Electrical generator (Synchronous or Asynchronous generator)
- Civil, electrical and mechanical auxiliaries, control panels etc.

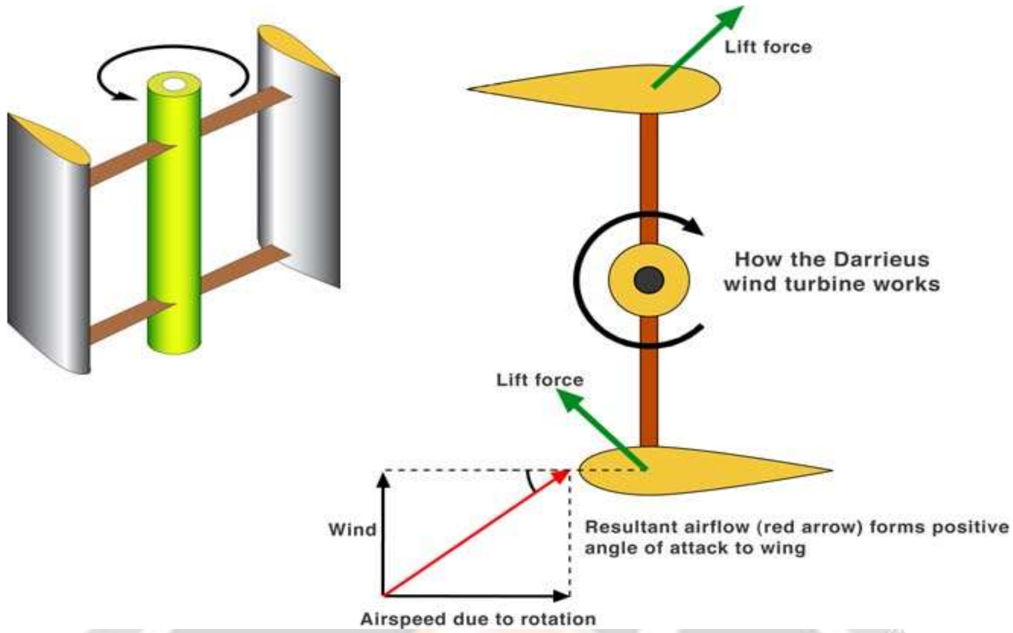


Figure No 3:- Forces And Rotation Blades

3. General Mathematical Expressions:-

3.1 Principal Operations:-
The speed ratio (l) is defined as:-

$$\lambda = \omega R/\mathrm{U}$$

A relation between the azimuth angle q, the angle of attack a and the speed ratio l has

been obtained from the velocity triangle , this relation is as follow:

$$\alpha = \tan^{-1}\{\left[\frac{\sin\theta}{\lambda + \cos\theta}\right]$$

If the airfoil is set at an angle of incidence a in a fluid flow and according to the standard airfoil theory, it will generate a lift force F_L normal to the free stream and a drag force F_D in the direction of the free stream. These lift and drag forces can then be resolved to get the tangential force F_T and the axial force F_N as shown in Fig. 3. The tangential force F_T has the instantaneous responsibility of the torque and the power outputs from the Darrieus turbine. For a Darrieus rotor of height H, a wind of incoming velocity U, the mechanical power P and the mechanical torque on the axis of a Darrieus turbine can respectively be written as follows:

$$C_m = \frac{T}{1/2\rho ARU^2}$$

and

$$C_p = \frac{P}{1/2\rho AU^2}$$

where C_m and C_p are respectively the torque coefficient and the power coefficient.

3.2 General mathematical expressions for aerodynamic analysis of straight-bladed Darrieus type VAWTs

Though the straight-bladed Darrieus-type VAWT is the simplest type of wind turbine, its aerodynamic analysis is quite complex. Before comparative analysis of the main aerodynamic models, the general mathematical expressions, which are common to most of the aerodynamic models, are described in this section.

3.2.1. Variation of local angle of attack:-

The flow velocities in the upstream and downstream sides of the Darrieus-type VAWTs are not constant as seen in Fig. 5. From this figure one can observe that the flow is considered to occur in the axial direction. The chordal velocity component Vc and the normal velocity component Vn are, respectively, obtained from the following expressions:

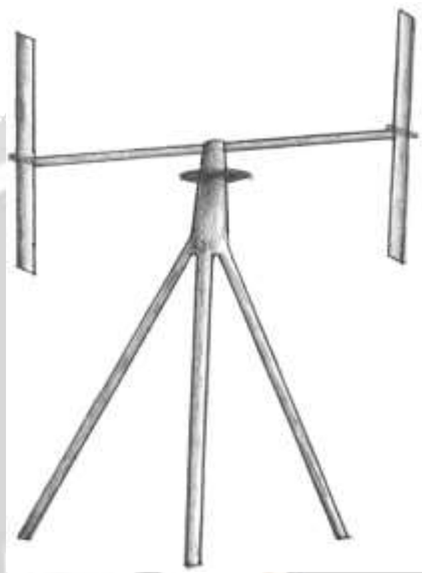


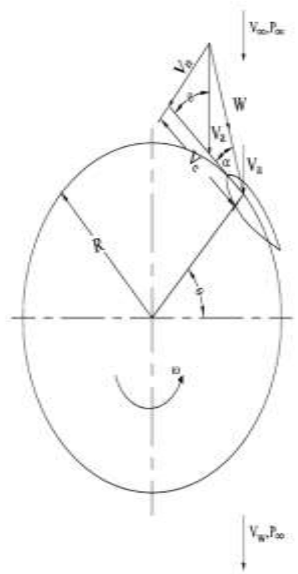
Figure No 4 -H-Darrius Rotor

$V_c = R\omega + V_a \cos\theta$

$V_n = V_{a+} \sin\theta$

where Va is the axial flow velocity (i.e. induced velocity) through the rotor, o is the rotational velocity, R is the radius of the turbine, and y is the azimuth angle. Referring to Fig. 5, the angle of attack (a) can be expressed as

$$\alpha = \tan^{-1}\left(\frac{V_n}{V_c}\right)$$



Substituting the values of Vn and Vc and non-dimensionalizing,

$$\alpha = \tan^{-1}\left[\frac{\sin\theta}{(R_\omega/V_\infty)/(V_a/V_\infty)+\cos\theta}\right]$$

where V1 is the free stream wind velocity. If we consider blade pitching then,

$$\alpha = \tan^{-1}\left[\frac{\sin\theta}{(R_\omega/V_\infty)/(V_a/V_\infty)+\cos\theta}\right]-\gamma$$

where g is the blade pitch angle.

3.2.2. Variation of local relative flow velocity

The relative flow velocity (W) can be obtained as

$$W = \sqrt{V_c^2 + V_n^2}$$

Inserting the values of Vc and Vn (Eqs. (1) and (2)) in Eq. (6), and non-dimensionalizing, one can find velocity ratio as,

$$\frac{W}{V_\infty} = \frac{W}{V_a}.\frac{V_a}{V_\infty} = \frac{V_a}{V_\infty}\sqrt{\left[\left(\frac{R_\omega}{V_\infty}/\frac{V_a}{V_\infty}\right)\cos\theta\right]} + sin^2\theta$$

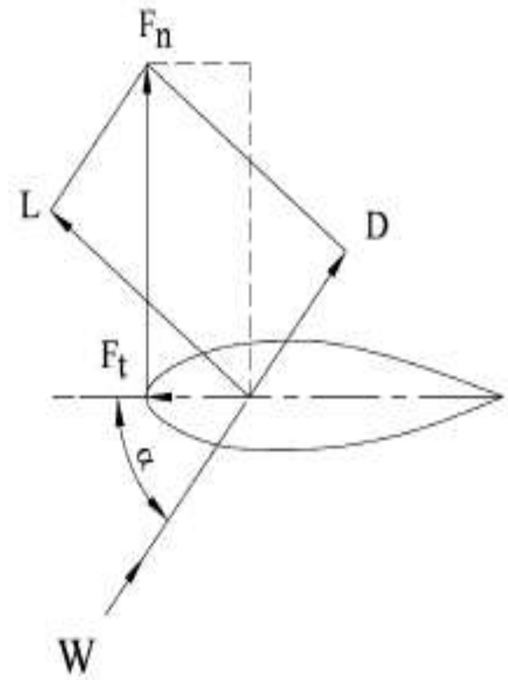


Fig No :-5 Force Diagram of a Blade Profile

3.2.3. Variation of tangential and normal forces:-

The directions of the lift and drag forces and their normal and tangential components are shown in Fig. 6. The tangential force coefficient (Ct) is basically the difference between the tangential components of lift and drag forces. Similarly, the normal force coefficient (Cn) is the difference between the normal components of lift and drag forces. The expressions of Ct and Cn can be written as

$$C_1 = C_1 \sin x - C_d \cos x$$

$$C_n = C_1 \cos x + C_d \sin x$$

The net tangential and normal forces can be defined as

$$F_1 = C_1 1/2 \rho CHW^2$$

$$F_n = C_n 1/2 \rho CHW^2$$

where r is the air density, C is the blade chord and H is the height of the turbine.

3.3 Calculation of total torque:-

Since, the tangential and normal forces represented by Eqs. (10) and (11) are for any azimuthal position, so, they are considered as a function of azimuth angle y. Average tangential force (Fta) on one blade can be expressed as

$$F_{ta} = \frac{1}{2\pi} \int_0^{2x} F_1(\theta) d\theta$$

The total torque (Q) for the number of blades (N) is obtained as

$$Q = ¼\ N_f t_{aR}$$

3.4 Power output:-

The total power (P) can be obtained as

$$P = Q.\omega$$

4. Design of vertical axis wind turbine

Design of VAWT is described below in three stages-first is selecting the suitable airfoil, second is modeling of the airfoil and other components in software tools like solid works, and third is fabricating the model by selecting appropriate material.

4.1 Airfoil Selection

In this design, NACA 0012 airfoil is selected, see in Fig. . (6) The selected airfoil is symmetrical and the four digits of any NACA series airfoil defines the wing profile by the following:

- Maximum camber as percentage of chord is described by the first digit.
- The distance of maximum camber from the airfoil leading edge in terms of percent of the chord is described by the second digit.
- Maximum thickness of the airfoil as percent of the chord is described by the last two digits.

From the above three points, the selected airfoil profile is described that it has no camber and it has 12 % thickness to its chord length ratio.

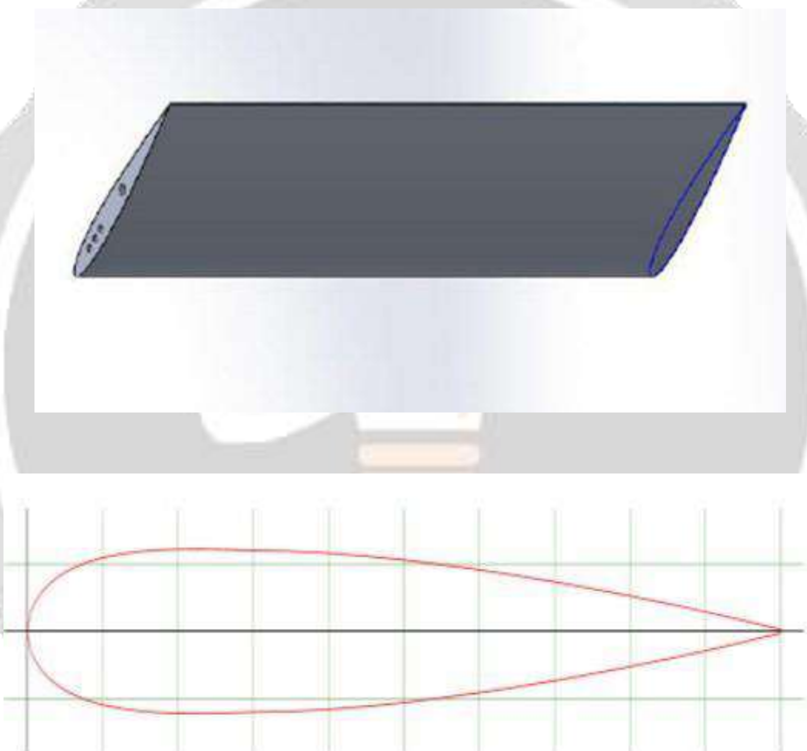


Fig No 6:- Model of Airfoil

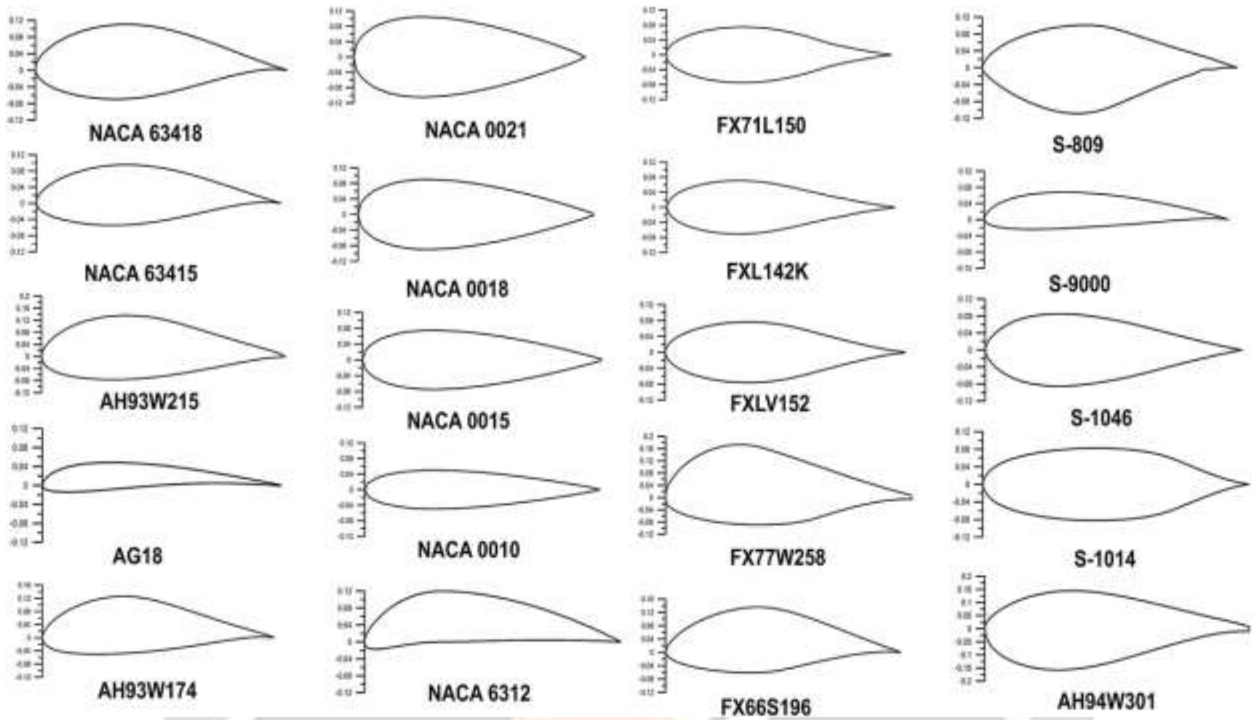


Fig No 7:- Series Of Airfoil

5. Methodology:-

5.1 Experimental investigations:-

Generally, the global performance of a H-rotor Darrieus turbine, identical to or derived from the conventional Darrieus rotor, has been investigated in such studies. Sometimes, visualizations of the flow in and around the rotor have been investigated. Quantitative information in such studies is also associated to the complexity of the flow in and around Darrieus turbines, in particular to the marked unsteadiness of the turbulent flow. Furthermore, boundary layer separation is an essential aspect affecting the efficiency of the rotor. Detailed aerodynamic investigations are rare and often do not allow the prediction of the energetic behavior of the rotor. However, some studies are of higher quality and give a relatively clear description of the aerodynamics of the conventional Darrieus rotor. Beyond pure aerodynamic studies of the airfoil, some attempts have already been documented to improve the performance of the Darrieus turbine; the main ideas and proposed improvements are summarized and discussed in Tabel-I

Figure 8 :- Aerodynamic Model at 600mm Height

Design	Gain	Description
Comparison of different turbine concepts for wind energy	3 different wind turbines have been compared; the horizontal axis wind turbine and two different concepts (Darrieus turbine and H-rotor)	VAWT and in particular H-rotor appear to be advantageous compared to horizontal axis wind of vertical axis wind turbines turbines in several respects
Trapezoidal-bladed turbine	No performance improvement	Reduction of mean stress and cyclic load amplitudes reduce significantly the fatigue, improving durability
Cycloidal Darrieus turbine	Improvement in performance of about 25%	Higher investment and running cost. The control mechanism consumes part of the output power
Combined Savonius-Darrieus type	Improved self-starting	More complex design

5.2 Main Component Of Straight Blade Vertical Axis Turbine:-

1. **Rigid base**: We have decided to provide square shape base of better thickness to provide support at the base to the whole set up, which will very useful to stand the VAWT unit on the roof of the house. The material we are using for this is Mild steel.

2. **Turbines:** The number of turbine rotor we are using here is one. After comparing the available categories of shapes of blade of rotor, We have finally decided to used SAVONIUS rotor semicircular blade shape due to its large surface area for impact of wind and easier construction. The no. of blade containing in rotor will be 6. The material for the blades of rotor will be Aluminum sheet due to its corrosive resistive property and other properties comparing to steel or plastic.

3. **Circular Platforms:** There are 3 circular platform i.e. For top and bottom of rotor and for fixed platform. These circular platforms will help in restriction for wind to go outside of turbine for maximum utilization of wind power content in the wind. The fixed platform at bottom of rotor and the bottom platform of the rotor located will carry the generator arrangement. The material suggested for these platforms is hard plastic or fiber.

4. **Bolts:** There will be four bolts for the hole drilled in the four corners of rigid base platform. It will helpful in fixing the set up on the roof. The material for bolt will be Mild Steel.

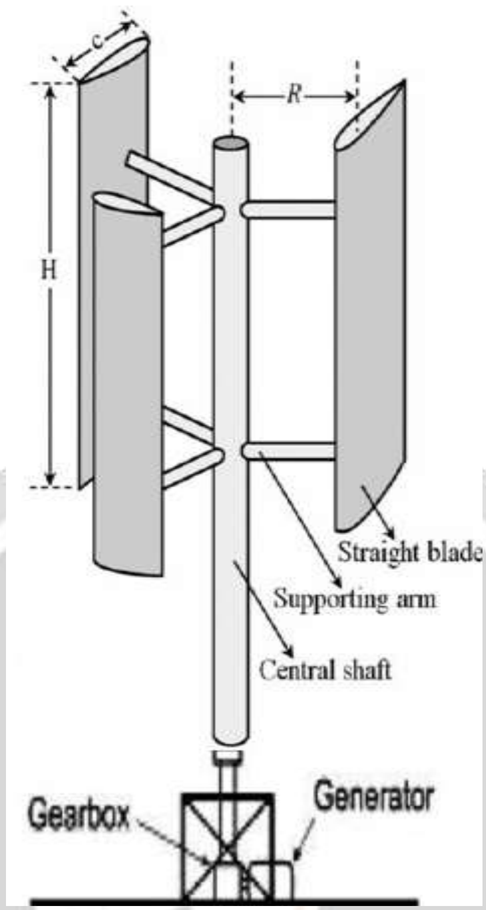


Fig No 9:- Setup of VAWT

6.Conclusion:-

The concept that we are using in SB_VAWT is in such a way that we should use in utilizing this renewable energy efficiently, and environmentally friendly. This, in turn will eliminate the environment hazard and improve health and life style. It is difficult to mount vertical-axis turbines on shafts, so they are often installed nearer to the base, such as the ground or a building rooftop. The wind speed is slower at a lower altitude, so less wind energy is available for turbine of a given size. Air flow near the ground and other objects can create turbulence, which can introduce issues of vibration, including noise and bearing wear which may increase the maintenance or shorten its service life. However, when a turbine is mounted on a rooftop, the building generally redirects wind over the roof and these can double the wind speed at the turbine. If the height of the rooftop mounted turbine shaft is approximately 50% of the building height, this will be almost optimum for maximum wind energy and minimum wind turbulence.

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